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Contents

Obituary: Associate Professor Jaroslav Jágr

We are deeply saddened to announce that Associate Professor Jaroslav Jágr, the first Dean of the Faculty of Economics at the Technical University of Liberec (1992–1996) and founder of the E&M Economics and Management journal, passed away on 22 April 2025 at the age of 92.

Associate Professor Jaroslav Jágr initiated the establishment of a new economics journal at the beginning of 1998. The journal was established because of the absence of professional periodicals dealing with applied economics and management in the Czech Republic at that time. Another intention was to enable the publication of quality papers, especially by junior researchers at regional faculties of economics. The possibility of publishing the journal in cooperation with other economic faculties was therefore pursued from the beginning. An agreement on the joint publishing of the new journal was concluded with the deans of the faculties of economics in Hradec Králové, Pardubice, Plzeň, Ústí nad Labem and Zlín. The first meeting of the Editorial Board, headed by Associate Professor Jaroslav Jágr, took place on 3 November 1998 in Liberec, and the journal's first issue was published at the end of the same year.

The journal received a positive response from the professional community, as evidenced by the increasing number of articles, authors and responses. The publishing team gradually grew to include other faculties from Karviná, Banská Bystrica and Košice. In 2003, the journal was transformed into a scientific journal and, in connection with internationalisation, gradually switched to publishing articles in English. In 2007, the journal was successfully evaluated externally and started to be indexed in the Scopus database. Since 2008, it has been included in the Social Sciences Edition of the Web of Science, and since 2010, it has been listed in Journal Citation Reports. In 2010, the journal was awarded an impact factor for the first time.

Twenty-seven years after the journal's founding, it is clear that Associate Professor Jágr's decision to conceive the journal as an open platform for exchanging professional and research knowledge, based on the collaboration of many universities, was far-sighted and visionary. The journal's openness to the outside world and the joining of forces of experts from different faculties distinguished it from a number of other periodicals that were established in the Czech Republic around the same time.

Associate Professor Jágr was an exceptional person who made an indelible contribution to the current form of the Faculty of Economics of the Technical University of Liberec and its strong place in the Czech university system. He was a distinctive personality with deep knowledge not only in his field but also with a broad overview across disciplines. He liked to get to know our region and always helped with advice and a kind word.

His passing is a loss to the entire university and academic community.

Honour his memory.

Miroslav Žižka
Editor in Chief

Multivariate time series models of development for countries with transitional economies and prospects for post-COVID growth

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Abstract: *The study aims to compare the economic achievements of the Visegrad Group (V4), the Baltic states (B3), Central Asia (CA4) and Balkan states (BA5), Kazakhstan on their way to joining the group of developed countries and to analyze the dynamics of their economic development. The results of studying the average annual growth rates of gross domestic product on the example of V4, B3, and Kazakhstan allowed for establishing the main patterns and trends of economic development in the pre-crisis, crisis, and post-crisis periods. The econometric modeling results indicate that an increase in employment levels contributes to per capita GDP growth. In turn, higher expenditures on domestic capital formation, the development of export-oriented industries, and the enhancement of regional specialization contribute to a more sustainable economic growth trajectory, as well as improved labor productivity, higher wages, and reduced unemployment. Poland and the Czech Republic exemplify this economic model. The study data confirm the possibility of solving the problem of countries with transitional economies entry into the number of developed countries by 2050 if the relevant conclusions are made from the analysis of the successful practice of V4 and B3 countries' development.*

Keywords: *Economic development, cointegrating regression, diversification, nonlinear growth, model.*

JEL Classification: *F00, F63, O10.*

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Introduction

After the collapse of the socialist system in the early 1990s, the countries of Eastern Europe and the former Soviet Union became part of the global economy. However, the transition to a market economy in many post-socialist countries has led to quite significant differences in the pace of economic development, as well as structural shifts in the economy. Today, many of them are faced with the dilemma of choosing the future model of economic development (Feldman et al., 2016). These countries, characterized by underdeveloped financial systems in the context of planned economies, are of considerable interest for studying the relationship between financial development and economic growth (Cojocaru et al., 2016). In the global context, the success of an economic transformation is determined by several factors, including political leadership, human capital, institutional development, and the country's innovation and competitiveness. These elements can have a positive impact on the formulation of effective public policies, economic growth, the creation of competitive advantages, the attraction of foreign direct investment, and overall management efficiency (Yudhoyono et al., 2024). Many post-communist countries are still in search of their preferred type of capitalism. During this process, a phenomenon known as the post-socialist developmental state has emerged, becoming a dominant model of institutional mechanisms and governmental policies in certain countries of the former socialist world (Bolesta, 2019).

The study of post-socialist social transformations in Eastern Europe reveals their inherent contradictions. Despite the achievements of social reforms in the region, substantial segments of the population have suffered as a result of the rapid transition to a market economy. The established economic and political order is criticized in public discourse for its high social costs. Furthermore, significant challenges persist in consolidating democracy across all Eastern European societies. Additionally, there are serious issues regarding the international competitiveness of the national economies in nearly all Eastern European societies (European Commission, 2010; Genov, 2021). Therefore, there is a pressing need and sustained scholarly interest in studying the success of the economic and political reforms undertaken during the process of market transformation and democracy-building in a vast number of post-socialist countries in Eastern Europe and the former USSR (Praščević, 2023). In a relatively short historical period, the former socialist countries – Czech Republic, Hungary, Poland, Slovakia (V4), and the former Soviet republics – Estonia, Latvia, and Lithuania (B3) were admitted to the OECD (2020). The V4 and B3 countries differ in their economic power and level of development (Dutta et al., 2019). This study aims to compare the economic achievements of the Visegrad Group countries (V4), the Baltic countries (B3), the Balkan Peninsula countries (BA5), and Central Asian countries (CA4) in their path toward integration into the global economy and to analyze the dynamics of their economic development.

Study limitations. The peculiarity of this article is an interrelated analysis of the three most important problems of economic development, which the V4 and B3 countries managed to solve. The article also strives to identify the main results of transformations and to compare them with the current practice of countries with transitional economies. The study also aims to find the necessary priority measures, the adoption of which will bring countries with transitional economies closer to developed countries. Only those indicators of economic development that were calculated without significant changes in the period 2000–2021 were used. This estimate was carefully designed to accurately capture the trends of recent years and reflect regional specificities.

1 Theoretical background

The aim of this study was to examine the patterns of economic development in four groups of countries with transitional economies. The countries under consideration differ in terms of initial conditions for reform, resource endowment, political environment, and other factors. The need for this study arises from the presence of numerous gaps in the literature, as previous investigations have failed to provide a definitive answer to the primary reasons for the diverse outcomes of economic transition in the post-Soviet region of former communist countries.

1.1 Contemporary issues in the development of post-socialist countries

Many post-communist states are still searching for their model of capitalism. However,

in contemporary academic research and literature, this issue seems to receive insufficient attention for various reasons. Specifically, there is a lack of thorough examination of the systemic and institutional mechanisms that have been evolving in the post-socialist world in recent years (Bolesta, 2019). Recent studies have explored the impact of various variables, including not only economic and social, but also geographic factors, on the success of transitioning to a market economy (Chowdhury et al., 2025). Researchers have found substantial cross-country variations in the degree of lag identified among Central and Eastern European (CEE) countries. These differences are attributable to the diverse models of post-Soviet capitalism that have evolved in these nations and their subsequent development following their accession to the European Union (Bárcena-Martín et al., 2025).

The majority of issues in contemporary economic theory and practice stem from divergent understandings of the role and interplay between the state and the market within the economy, as well as the ideological drive to influence economic policy (Delibasic, 2022). The post-socialist transformation in Eastern Europe and the former Soviet Union (EEFSU) is often examined from a neo-Schumpeterian perspective. The crux of this approach lies in understanding that the challenges of modernization in the post-socialist region cannot be comprehended solely through the lens of transitional economic theory (Radosevic, 2022).

Overall, these countries have, to varying degrees of success, undergone periods of adaptation based on the importation or imitation of institutions from established market economies. Assessing the experience of systemic changes following the accession of some of them to the EU and the 2008 crisis, as well as analyzing the contemporary development challenges of different socio-economic models (such as “dependent capitalism” in Eastern and Central Europe and the Balkans, contrasting with the “administrative regime” in Russia and the “dictatorship with the market economy” in Belarus), this can be explained by the growing divergence of socio-economic trajectories in these countries (Chepurenko & Szanyi, 2022). The main body of research on this topic focuses on a relatively narrow range of issues related to the financial sector, liberal reforms, and factors contributing to economic growth. However, there is a lack of studies on the relationship between levels of well-being, on the one hand, and indicators such as labor utilization, capital formation, and exports, on the other, in post-Soviet countries.

1.2 Experience of transformation in post-socialist countries

The countries of Central and Eastern Europe are characterized by great diversity in political and economic potential, population size, and territorial size. This diversity is complemented by differences in historical, social, and cultural development, including religious, linguistic, national, and ethnic (Jasiecki, 2020).

For a long time, the main problems in the development of countries that have transitioned to a market economy have usually been associated with institutional difficulties. Recent studies on this issue include the works of Bazhan (2019), Clague (2017), Eydam and Gabriadze (2020), Mardanov (2020).

Much of the economic development results achieved, according to Clague (2017), depend largely on the chosen economic policies and the way they are implemented by public institutions. Efficiency is also affected by mechanisms for protecting property rights and contract enforcement in the business community, as well as models of participation in community organizations.

On the other hand, the transition from a socialist economy to a capitalist economy led many formerly socialist countries to a sharp decline in their technological competencies, technology transfer, and research activities after the 1990s (Švarc & Dabić, 2019). At the same time, the role of human capital in the global economy has increased greatly, as evidenced by the research conducted by Baser and Gokten (2019). For many countries, including post-socialist countries, this is one of the most important challenges of our time, which impacts sustainable economic development.

The emerging initial conditions and circumstances during the period of 1989–1990, the legacy of the former socialist system, as well as the processes of transition and integration into the EU marked by exceptional institutional reforms, have led to the emergence of the so-called “dependent capitalism” model in Central and Eastern Europe in the 2000s. Although this model is unique in terms of the level of understanding of its complexity, it represents

various variants associated with the forms of dependencies characterizing it (Magnin & Nenovsky, 2022).

The Baltic states initiated the transition from a socialist economy to a market-oriented system in the early 1990s and have since established a modern service economy with a high GDP per capita. This successful transition in these countries was facilitated by the effective liberalization of the financial sector, the development of transportation and logistics infrastructure, and institutional reforms. Since gaining independence, the Baltic countries have faced challenges in transitioning their economies from a centralized planning model to a market system, including institutional issues and economic and legal imperfections in company and competition legislation. However, the Baltic countries have successfully established a diverse economic development model characterized by flexibility and competitiveness, particularly within the small and medium-sized business sectors (Bitė et al., 2022).

However, there is also an example of limited success related to Latvia, where the phenomenon of financialization has firmly established itself in the country's banking sector. The concept of financialization is closely associated with the increasing share of financial services in national income and represents a complex and dynamic phenomenon (Pataccini, 2023). The markets of these countries offer opportunities for both domestic and international investors to make financial investments and diversify their international portfolio (Bartha & Valuch, 2024).

The civil war in the former Yugoslavia during the 1990s had a negative impact on economic reform and the transition to a market economy. However, Croatia and Montenegro, among other former Yugoslav republics, were able to overcome the crisis and implement necessary reforms. As a result, these countries experienced higher GDP growth per capita than other Balkan nations.

In general, for many Balkan countries during this period, complex transitional processes of state-building lasting over three decades became characteristic, along with a persistently low level of economic development compared to Western, Central, and Eastern European countries, as well as a political orientation towards European Union membership. However, tangible development effects in individual countries were largely not achieved due to corruption and other institutional, economic, social, and legal challenges (Miljković, 2023). Recent research shows that in Central and Eastern European countries that are part of the EU, the link between real wages and labor productivity has been more positive compared to the countries of Southeastern Europe, mainly represented by the Balkan Peninsula countries, where wage increases do not automatically lead to significant labor productivity growth and, in some cases, even have a reverse effect of reduction (Trenovski et al., 2023). These countries tend to prioritize the development of tourism and the service sector (Tiwari et al., 2024).

The economic outlook for the Western Balkan region is not promising with regard to the prospects for rapid economic growth. For instance, the GDP per capita of the "most developed" country in the region, Montenegro, is still lower than the GDP of Bulgaria, the least developed member state of the European Union. Additionally, it is unlikely that the investment surge and GDP growth witnessed in the Visegrad Group and Baltic states prior to their accession to the EU will be replicated in the Balkan region (Kurecic & Haluga, 2022).

During the transition period, Central Asian countries implemented stabilization-oriented and structural reforms through monetary policy, the introduction of national currencies, price liberalization, privatization, and fiscal adjustments. Kazakhstan and Kyrgyzstan swiftly made the transition to market-based systems through various reforms, whereas Uzbekistan and Turkmenistan were slower. Tajikistan, on the other hand, was affected by internal civil strife, which also delayed its transition to a market economy. Consequently, these stabilizing and structural measures have yielded mixed results for Central Asian states (Yadav, 2016).

The transformation of post-socialist economies Central Asian countries (CA4) as accompanied by structural shifts. At the same time, not all countries managed to create a competitive diversified economy. One example of such countries is Kazakhstan, where economic development remains highly dependent on the state of the commodity sectors and the global market situation. In this regard, Kazakhstan needs to obtain the results of a comparative analysis of its socio-economic indicators with similar indicators of these countries (Dutta et al., 2019). Thus, the main purpose of this

article is to compare the economic achievements of the V4, B3 countries, and Kazakhstan on their way to joining the group of developed countries and to analyze the dynamics of their economic development (Dnishev & Alzhanova, 2014). A review of the available scientific literature shows that there is no unequivocal assessment of the results of transformational reforms in post-socialist countries. Some researchers argue that the transition from a planned economy to an open market economy has led to an increase in national income in post-socialist countries (Ko & Min, 2019). The primary impediments to political reform and economic diversification in the five Central Asian countries are internal and external geopolitical factors, as well as deep-seated institutional weaknesses within each country. These weaknesses are particularly evident in areas where economic governance intersects with authoritarian political systems and underdeveloped legal institutions (Batsaikhan & Dabrowski, 2017).

2 Research methodology

This research is based on the comparative study and international analysis of economic development in post-Soviet countries, grouped into corresponding geographical categories. The study was conducted in several stages. The first stage involved determining the criteria for selecting countries to examine their transition from a planned economy to a market-based system. The second stage involved justifying the period for studying the dynamics of change in economic development. Finally, the third stage was the collection of data.

For comparative analysis, a total of 16 post-socialist countries were carefully chosen and divided into four regional groups. The Visegrád Group (V4) consisted of the Czech Republic, Hungary, Poland, and Slovakia. The Baltic countries (B3) included Estonia, Latvia, and Lithuania. The Balkan Peninsula countries (BA5) encompassed Albania, Croatia, Montenegro, Serbia, and North Macedonia. Central Asia (CA4) was represented by Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan. These country selections were driven by the research objectives, aiming to examine countries with varying levels of economic development that shared geographical proximity and a common communist history. The following abbreviations of geographical names and indicators were used (Tab. 1).

Tab. 1: Abbreviations of geographical names and indicators – Part 1

Geographical names	Abbreviations	Indicators	Abbreviations
Albania	ALB	**GDP per capita (current USD)**	*GDPPC*
Estonia	EST	**GDP growth (annual %)**	*GDPGA*
Czechia	CZE	**Labor force, total (% of total population)**	*UL*
Croatia	HRV	**Gross capital formation (% of GDP)**	*GCF*
Hungary	HUN	**Exports of goods and services (% of GDP)**	*EGSGDP*
Kazakhstan	KAZ		
Kyrgyz Republic	KGZ		
Lithuania	LTU		
Latvia	LVA		
North Macedonia	MKD		
Montenegro	MNE		
Poland	POL		
Serbia	SRB		

Tab. 1: Abbreviations of geographical names and indicators – Part 2

Geographical names	Abbreviations	Indicators	Abbreviations
Slovakia	SVK		
Tajikistan	TJK		
Uzbekistan	UZB		
OECD members	OECD		
World	WLD		
Eastern Europe	EE		
Central and Eastern Europe	CEE		
Former Soviet Union	FSU		
Visegrád Group	V4		
Baltic countries	B3		
Balkan Peninsula countries	BA5		
Central Asia	CA4		
European Union	EU		
Commonwealth of Independent States	CIS		

Source: own

Additionally, abbreviated names of indicators and three-digit country identifiers were used when constructing graphical figures. The indicator GDP per capita (current USD) was abbreviated as GDPPC and accompanied by a country identifier. For example, for Albania, it appears as GDPPCALB. Other indicators used also received abbreviated names. In calculations, the indicator of the share of the national economy in the global economy was also used. It was calculated as the percentage of national GDP relative to global GDP. The data for the research were obtained from the World Bank national accounts data, and OECD National Accounts data files: i) GDP (current USD) – World Bank national accounts data, and OECD National Accounts data files (2023), official web site, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD; ii) GDP per capita (current USD) – World Bank national accounts data, and OECD National Accounts data files (2023), official web site, https://data.worldbank.org/indicator/NY.GDP.PCAP.CD; iii) GDP per capita growth (annual %) – World Bank national accounts data, and OECD National Accounts data files (2023), official web site, https://data.worldbank.org/indicator/NY.GDP.PCAP.KD.ZG; iv) gross capital formation (% of GDP) – World Bank national accounts data, and OECD National Accounts data files (2023), official web site, https://data.worldbank.org/indicator/NE.GDI.TOTL.ZS; and v) unemployment, total (% of total labor force) – World Bank national accounts data, and OECD National Accounts data files (2023), official web site, https://data.worldbank.org/indicator/SL.UEM.TOTL.ZS.

Furthermore, the selection of these countries took into consideration the methodological approaches of other researchers (Alexiou et al., 2020; Faghih et al., 2019).

Additionally, these countries needed to have accessible and relevant statistical information available for the period spanning from 2000 to 2021. The chosen research period was necessary to account for the influence of global factors, internal reforms, and the availability of comprehensive economic data.

The study of the average annual GDP growth rate of V4, B3, BA5, and CA4 allowed studying the main patterns and trends

of economic development in the pre-crisis, crisis, and post-crisis periods. Using the World Bank's World Development Indicators database, the authors analyzed the average annual rates of change in GDP, unemployment rate, gross capital formation as a percentage of GDP, and the size of the national economy in the global economy over twenty-two years (2000–2021). The pre-crisis period encompassed data on the average annual growth rates of the studied economies from 2000 to 2007, the crisis period from 2008 to 2009 and up to 2014, and the post-crisis contemporary period from 2015 to 2021.

Methods of statistical data processing: comparative analysis of GDP per capita growth dynamics (current USD) and GDP growth (annual %) dynamics, dynamics of changes in the share of national economies of individual countries and regional groups of countries in the global GDP (%). The calculations were conducted using the methodology developed by the World Bank (2025).

This paper uses mixed methods, which include comparative and correlation analysis. For comparative analysis, it is important to choose the right countries, which successfully transformed their former planned economy into a market economy. It is well known that the economic criteria by which a group of developed countries is distinguished are debatable. In recent studies, as well as in scientific literature and practice, several criteria have been used by international organizations to classify countries. These are, first of all, the achieved level of gross domestic product (GDP) per capita, the human development index, as well as geographical, economic, and other criteria for grouping the countries. In this study, the authors believe that GDP per capita does not fully reflect the nature of economic growth. The impact of economic growth on living standards is best judged by several indicators, including per capita income.

This study assumed the presence of a relationship between GDP dynamics and changes in the unemployment rate, as previously identified in the work (Bartolucci et al., 2018). The examination of the relationship between economic growth and unemployment in Eastern European countries is determined using tools of regression analysis (Soylu et al., 2018).

The cointegration (Engle-Granger) method was used to construct a model for 16 studied countries. The Engle-Granger cointegration technique enabled the identification of measurable effects when establishing long-term correlations between the time series of analysed economic variables, which are typically non-stationary (Łącka et al., 2020).

Cointegrating regression was conducted using Engle-Granger test, which estimates a lag-augmented regression of the form equation:

$$(1 - L)\, y = b_0 + (a - 1) \cdot y(-1) + \cdots + e \quad (1)$$

where: dependent variable: GDP per capita (current USD) – GDPP; independent variable: labor force, total (% of total population) – UL; gross capital formation (% of GDP) – GCF; exports of goods and services (% of GDP) – EGSGDP.

The research focuses on unemployment and its relationship with the level of prosperity based on GDP per capita. To examine this relationship, nonlinear regression models were constructed, considering the interplay between GDP per capita and the unemployment rate. Specialized scientific software Gretl was used for the analysis, along with the statistical analysis tools, applications, and functions provided by Microsoft Excel 2021 Professional Plus. Gretl is free, open-source software. It is a cross-platform software package for econometric analysis.

3 Results and discussion

This study analyzed 16 countries to evaluate the results of their economic reform efforts. The analysis revealed that by the year 2021, only eight of the sixteen countries under study had managed to achieve a GDP per capita level above the global average. This outcome is inconsistent with what might be expected from these countries following more than two decades of economic growth. Therefore, it is essential to understand the factors and challenges that have led to this lag, as well as to identify ways to address them.

3.1 Results

A comparative analysis of economic development in countries with transition economies revealed significant disparities in the outcomes achieved during the transition to a market economy. Long-term observations of post-socialist countries with transitional economies indicate the persistence of a nonlinear trend in their economic development. For most countries, the period of economic growth from 2000 to 2007 was

the most stable, as evidenced by the changes in the dynamics of the GDP per capita indicator (Fig. 1).

The comprehensive examination of GDP per capita dynamics spanning 22 years unveils notable variations in the levels among countries, with disparities that emerged in 2000 persisting in certain countries to this day. This disparity is particularly evident in the Balkan and Central Asian regions, where market reform processes have been less successful. As an example, when comparing the average GDP per capita of Montenegro and North Macedonia in 2000, a marginal distinction was observed. Montenegro recorded a figure of USD 1,627.1, whereas North Macedonia reported USD 1,861.9, indicating a minimal difference of only USD 234.8. However, by 2022, the GDP per capita in Montenegro and North Macedonia had reached USD 9,465.7 and USD 6,694.6, respectively, with a growing difference between these countries of USD 2,771.1 (Tab. 1). Similarly, Serbia experienced an increase in GDP per capita from USD 914.8 to USD 9,230.2 during the same period. Another example can be observed in Kazakhstan, which achieved a high level of progress in GDP per capita, reaching USD 10,373.8 in 2021, surpassing the values of other Central Asian countries and most Balkan countries, except for Croatia, where this indicator reached USD 17,685.3.

The example of Kazakhstan exemplifies how post-socialist countries have successfully utilized their opportunities, resources, and time to implement extensive reforms and transition to a modern market economy. A main factor in evaluating their achievements is the effective utilization of domestic labor resources and an examination of migration trends. In contrast to neighboring Central Asian countries, namely Uzbekistan, Kyrgyzstan, and Tajikistan, where significant levels of unemployment and labor outflows have been observed, Kazakhstan's adept policy framework for economic reforms and facilitation of a favourable investment climate has enabled the country to sustain and further cultivate its industrial sector. As a result, Kazakhstan has been able to maintain stable employment rates and a low unemployment

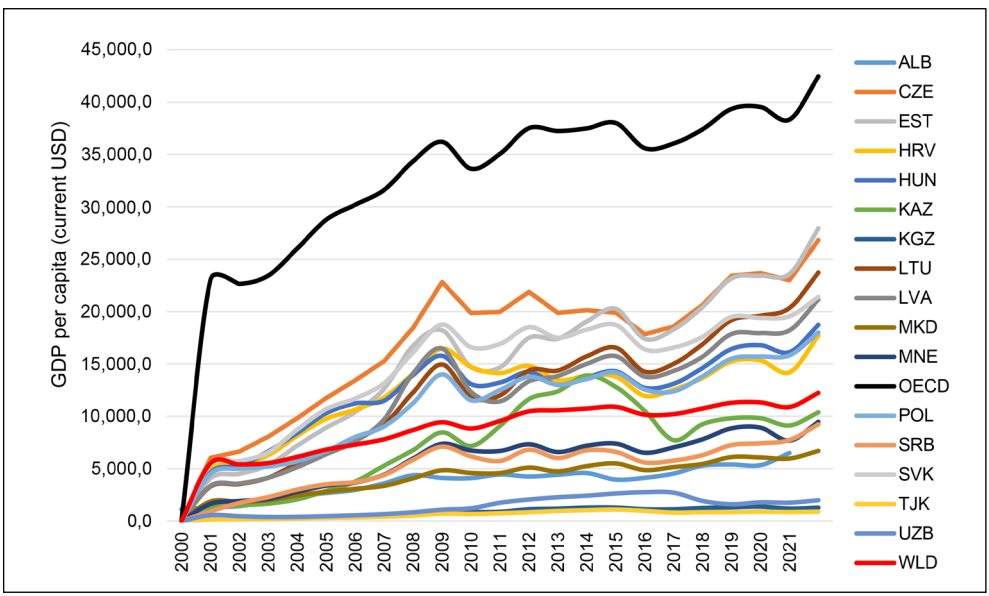

Fig. 1: **Comparative analysis of GDP per capita growth dynamics in V4, B3, BA4, and CA4 countries (2000–2021)**

Source: Prepared using GDP per capita (current USD) World Bank national accounts data, and OECD National Accounts data files (2023)

rate over the past two decades, while simultaneously achieving strong economic growth rates (Tab. 2).

One can contend that the attainment of sustainable economic development in nations experiencing substantial per capita GDP growth relies on enhanced efficiency in harnessing labor resources. Essentially, considering the transition from the resource-based industrial economy to the global digital economy that commenced in the 2000s, human capital and employment emerge as pivotal components of sustainable economic growth, despite the influence of persistent crises and geopolitical conflicts. On the other hand, the financial crisis of 2008 and the subsequent recession had a detrimental impact on economic growth.

Over the analyzed period from 2000 to 2021, the average annual economic growth attained its highest values in Kazakhstan in 2001 at 13.5%, Croatia in 2021 at 13.1%, Montenegro in 2021 at 12.4%, Latvia in 2006 at 12.0%, Lithuania in 2007 at 11.1%, and Tajikistan in 2003 at 11%. Conversely, the most significant economic contraction was observed in Montenegro in 2020, where this indicator reached its lowest point at −15.3%. Estonia, Latvia, and Lithuania also experienced substantial declines in 2009, with reductions of −14.6, −14.3, and −14.8%, respectively (see Fig. 2).

Tab. 2: Comparative analysis of GDP per capita growth levels (current USD) in the V4, B3, BA4, and CA4 countries (2000–2021)

	2000	2021	Growth of GDP per capita (%)
High progress			
Estonia	4,070.6	27,943.7	6.9
Czechia	6,029.0	26,821.2	4.4
Lithuania	3,293.2	23,723.3	7.2
Slovakia	5,426.6	21,391.9	3.9
Latvia	3,361.6	21,148.2	6.3
Hungary	4,624.3	18,728.1	4.0
Poland	4,501.5	17,999.9	4.0
Croatia	4,880.6	17,685.3	3.6
Kazakhstan	1,229.0	10,373.8	8.4
Average progress			
Montenegro	1,627.1	9,465.7	5.8
Serbia	914.8	9,230.2	10.1
North Macedonia	1,861.9	6,694.6	3.6
Albania	1,126.7	6,492.9	5.8
Little progress			
Uzbekistan	558.2	1,983.1	3.6
Kyrgyz Republic	279.6	1,276.7	4.6
Tajikistan	137.2	897.0	6.5
For comparison			
OECD members	23,026.1	42,446.9	1.8
World	5,507.4	12,236.6	2.2

Source: Prepared using GDP (current USD) World Bank national accounts data, and OECD National Accounts data files (2023)

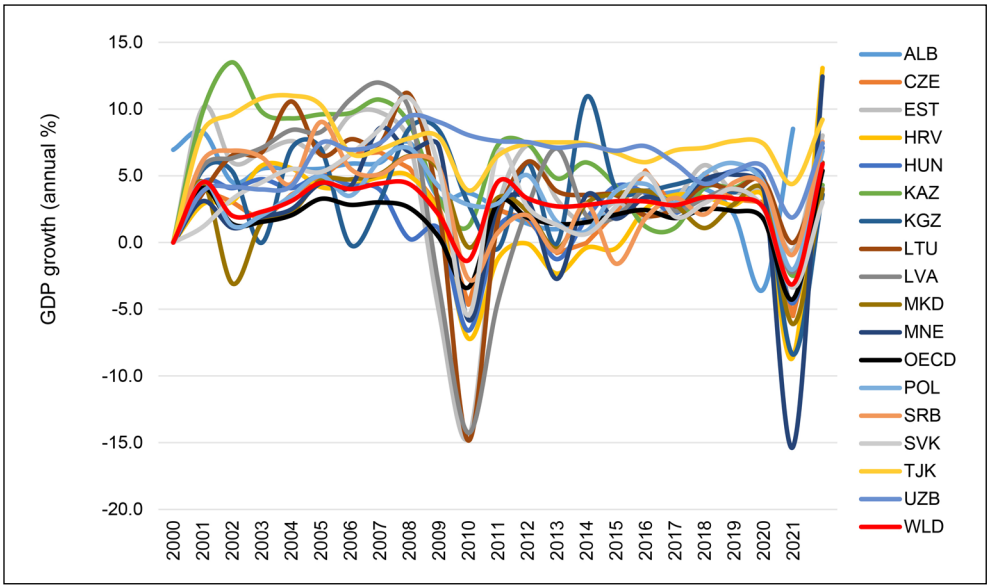

Fig. 2: Comparative analysis of GDP growth dynamics in V4, B3, BA4, and CA4 countries (2000–2021)

Source: Prepared using GDP per capita growth (annual %) World Bank national accounts data, and OECD National Accounts data files (2023)

The comparative analysis reveals a non-linear nature of economic growth. In specific years, the Baltic countries, as well as Montenegro and Croatia, exhibited the highest extremes of fluctuations between positive and negative economic growth rates. This can be attributed to one of the key challenges faced by countries with transitional economies, namely the unevenness of their economic development, which further widens the existing gap between them. The influence of the so-called "dependent capitalism" model is evident, where economic growth is directly linked to foreign investment inflows (e.g., Poland, Czech Republic, Slovakia, Hungary, Kazakhstan). Another variant of this model can be the dependence of a country's economy on the size of remittances from migrant workers (e.g., Tajikistan, Kyrgyzstan, Albania).

However, the economic development model based on "dependent capitalism" is preferable compared to the dependence of a country's economy on remittances from migrant workers, as it allows for the preservation of employment and the development of the national economy. This can also be observed from the analysis of countries' relative changes in GDP per capita compared to the global average (Tab. 3).

Central European countries belonging to the so-called "Visegrád Group" and the post-Soviet countries in the Baltic region have achieved the greatest success. The average GDP per capita in the Czech Republic from 2015 to 2021 exceeded the global level by a factor of 2, in Slovakia by nearly 1.7 times, in Hungary by 1.4 times, and in Poland by 1.3 times. Among the Baltic countries, Estonia had the highest indicator, surpassing the global average by a factor of 2, while Latvia and Lithuania exceeded it by 1.7 times. In Central Asia, Kazakhstan had the highest indicator. However, these countries still strive to reach the high levels of the OECD group, which remain currently unattainable for them. At the same time, the countries of the Balkan Peninsula and Central Asian countries noticeably lagged behind the post-socialist countries of Central Europe and the Baltic states in this indicator, failing to reach the average global level of GDP per capita, except for Croatia.

Tab. 3: Relative indicator of GDP per capita compared to the global average (%)

	2000–2007	2008–2014	2015–2021	2015–2021 to 2000–2007
V4				
Czechia	168.2	204.8	200.4	32.1
Hungary	135.3	138.0	141.2	5.9
Poland	104.2	131.3	135.1	30.9
Slovakia	146.9	177.7	169.7	22.8
B3				
Estonia	131.3	172.8	200.8	69.5
Latvia	111.8	153.2	170.3	58.6
Lithuania	98.8	141.5	167.9	69.1
BA5				
Albania	32.5	42.9	45.7	13.2
Croatia	133.5	143.6	131.0	−2.6
Montenegro	48.7	69.9	73.2	24.5
North Macedonia	40.3	49.0	52.5	12.2
Serbia	47.7	64.1	64.1	16.4
CA4				
Kazakhstan	47.3	107.0	86.7	39.4
Kyrgyz Republic	6.5	10.8	11.2	4.7
Tajikistan	4.3	8.6	7.9	3.7
Uzbekistan	8.1	19.0	18.9	10.8
Global Level				
OECD members	413.9	361.9	349.7	−64.2
World	100.0	100.0	100.0	–

Source: Prepared using GDP per capita (current USD) World Bank national accounts data, and OECD National Accounts data files (2023)

The study indicates that the implemented reforms and processes of post-socialist transformation have contributed to enhancing the competitiveness of national economies. However, the effects have varied, as demonstrated by the changes in the share of national economies of individual countries and regional groups of countries in the global GDP (Tab. 4).

During the comparative analysis of two periods, namely 2000–2007 and 2015–2021, it was observed that the collective representation of V4 countries in the global economy witnessed growth from 1.216% to 1.246%. Poland made the greatest contribution, with its share in the world economy rising to 0.668%. The share of Baltic countries in the global economy experienced a slight increase of 0.021%. Lithuania accounted for the most noticeable growth at 0.011%, followed by Estonia at 0.07%. The share of the Balkan countries decreased from 0.177% to 0.165%, primarily due to Croatia. However, the largest increase in the share of the global economy, following the Visegrád Group countries, was observed in the four Central Asian countries. Their share rose from 0.153% to 0.306%.

Tab. 4: Dynamics of changes in the share of national economies of individual countries and regional groups of countries in the global GDP (%)

	2000–2007	2008–2014	2015–2021	2015–2021 to 2000–2007
Czechia	0.266	0.304	0.277	0.011
Hungary	0.212	0.194	0.180	−0.032
Poland	0.616	0.707	0.668	0.053
Slovakia	0.122	0.136	0.121	−0.002
Total V4	1.216	1.341	1.246	0.030
Estonia	0.028	0.032	0.035	0.007
Latvia	0.035	0.041	0.039	0.003
Lithuania	0.051	0.061	0.062	0.011
Total B3	0.114	0.134	0.135	0.021
Albania	0.015	0.018	0.017	0.002
Croatia	0.089	0.087	0.070	−0.020
Montenegro	0.005	0.006	0.006	0.001
North Macedonia	0.013	0.014	0.014	0.001
Serbia	0.055	0.066	0.058	0.003
Total BA4	0.177	0.191	0.165	−0.012
Kazakhstan	0.111	0.252	0.207	0.096
Kyrgyz Republic	0.005	0.008	0.009	0.004
Tajikistan	0.005	0.010	0.009	0.005
Uzbekistan	0.032	0.079	0.081	0.049
Total CA4	0.153	0.349	0.306	0.153
OECD members	79.113	66.506	61.853	−17.260
World	100.000	100.000	100.000	–

Source: Prepared using GDP (current USD) World Bank national accounts data, and OECD National Accounts data files (2023)

Analyzing the indicators in Figs. 1–2, one can see that in the pre-crisis period (2000–2007), GDP growth in all countries under consideration was significantly higher than in the post-crisis period (2010–2019). Besides, in all the compared countries, the average annual GDP growth rate in the pre-crisis period was significantly higher than that of the OECD group as a whole. In 2020, significant impacts on economic development were observed due to the restrictions associated with the COVID-19 pandemic, which adversely affected economic growth. This is explained by the fact that the post-socialist economies in the period 2000–2007, thanks to investments by transnational companies, the transfer of a separate assembly production, as well as significant financial support from the EU budget and access to its markets, were able to recover faster after the crisis of the early 90s due to the collapse of the socialist system. Kazakhstan had the highest growth rates in this group due, on the one hand, to the favourable situation on world commodity markets, and on the other hand, to maintaining state control over the processes of transition to the market and a more competent policy of privatization of state property.

By considering GDP per capita as a significant criterion to evaluate the effectiveness of the chosen reform agenda and economic development in each post-socialist country and by comparing it with other indicators, we can observe a correlation with the exports of goods and services (% of GDP), unemployment rate, the proportion of gross capital formation in GDP, and the size of the national economy as measured by its relative contribution to the global economy (Tab. 5).

Except for Hungary, all countries exhibited a discernible correlation between GDP per capita and the examined factors. Particularly high levels of unemployment were observed in Balkan countries in the 2000s, as well as in Poland, Tajikistan, Kazakhstan, and Uzbekistan. Essentially, a high unemployment rate indicates the dominance of an inefficient model of economic development in a country where structural problems and low competitiveness manifest through unemployment. Additionally, it suggests the irrational use of one of the main highly productive resources of the modern post-industrial digital economy – human capital.

The cointegration-based modelling technique is most appropriate for analyzing the impact

Tab. 5: Correlation index (*r*) of dependency between GDP per capita (USD) and factors

	Exports of goods and services (% of GDP)	Labor force, total (% of total population)	Gross capital formation (% of GDP)	Share of the national economy in the world economy (% GDP of global economy)
V4				
Czechia	0.77	−0.02	−0.65	0.67
Hungary	0.72	0.78	−0.02	0.17
Poland	0.92	0.84	0.04	0.72
Slovakia	0.89	0.84	−0.70	0.58
B3				
Estonia	0.67	0.94	−0.31	0.87
Latvia	0.80	0.88	−0.28	0.69
Lithuania	0.89	0.76	−0.08	0.81
BA5				
Albania	0.82	0.69	−0.63	0.74
Croatia	0.49	0.61	−0.03	0.13
Montenegro	0.28	0.73	0.53	0.87
North Macedonia	0.93	0.94	0.93	0.78
Serbia	0.83	0.06	0.58	0.68
CA4				
Kazakhstan	−0.58	−0.04	−0.07	0.99
Kyrgyz Republic	−0.21	−0.72	0.86	0.99
Tajikistan	−0.96	0.20	0.82	0.99
Uzbekistan	−0.86	0.48	0.39	0.99

Source: Prepared using GDP per capita (USD) World Bank national accounts data, and OECD National Accounts data files (2023); labor force, total (% of total population) World Bank national accounts data, and OECD National Accounts data files (2023); gross capital formation (% of GDP) World Bank national accounts data, and OECD National Accounts data files (2023); GDP (current USD) World Bank national accounts data, and OECD National Accounts data files (2023); exports of goods and services (% of GDP) World Bank national accounts data, and OECD National Accounts data files (2023)

of labor, capital formation, and exports on GDP per capita. This statistical measure describes a long-term, stable relationship between two or more variables in a time series, even when these variables are individually non-stationary. Utilizing this approach to examine changes over the 2000–2021 period, the study revealed statistically significant variations between the variables under consideration. For instance, in the Visegrad Group (V4) countries, a high GDP per capita has been achieved through increased exports of goods and services (Tab. 6).

Tab. 6: Cointegrating regression in the countries of the Visegrad Group (V4)

		Coefficient	Std. error	*T*-ratio	*p*-value
Czechia (CZE)	Dependent variable: *GDPPCCZE*				
	Const	17,820.700	17,153.700	1.039	0.313
	ULCZE	−1,217.570	406.046	−2.999	0.008***
	GCFCZE	−274.699	411.957	−0.667	0.513
	EGSGDPCZE	219.731	102.876	2.136	0.047**
	R-squared	0.741	–	–	–
	Durbin-Watson	0.365	–	–	–
Hungary (HUN)	Dependent variable: *GDPPCHUN*				
	Const	−21,351.400	11,832.400	−1.804	0.088*
	ULHUN	156.040	332.378	0.047	0.963
	GCFHUN	434.150	309.433	1.403	0.178
	EGSGDPHUN	302.417	579.278	5.221	0.000***
	R-squared	0.609	–	–	–
	Durbin-Watson	0.497	–	–	–
Poland (POL)	Dependent variable: *GDPPCPOL*				
	Const	3,981.050	8,090.620	0.492	0.629
	ULPOL	−362.009	135.772	−2.666	0.016*
	GCFPOL	123.192	188.411	0.654	0.522
	EGSGDPPOL	207.701	873.178	2.379	0.029**
	R-squared	0.915	–	–	–
	Durbin-Watson	0.855	–	–	–
Slovakia (SVK)	Dependent variable: *GDPPCSVK*				
	Const	12,949.000	7,245.030	1.787	0.091*
	ULSVK	−388.359	151.591	−2.562	0.020**
	GCFSVK	−286.056	151.908	−1.883	0.076*
	EGSGDPSVK	181.636	506.160	3.589	0.002***
	R-squared	0.879	–	–	–
	Durbin-Watson	0.699	–	–	–

Note: Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; *GDPPC* – GDP per capita (current USD); *UL* – labor force, total (% of total population); *GCF* – gross capital formation (% of GDP); *GCF* – exports of goods and services (% of GDP).

Source: Prepared using GDP per capita (current USD) World Bank national accounts data, and OECD National Accounts data files (2023); unemployment, total (%x of total labor force) World Bank national accounts data, and OECD National Accounts data files (2023)

The proportion of labor resources within the total population in the Czech Republic and Poland was also found to have a statistically significant influence. Both countries have pursued active policies to attract migrant workers to their economies. This has enabled them to create export-oriented economies and considerably increase GDP per capita. Poland, in particular, has achieved the greatest benefit from attracting migrant labor, focusing on capital accumulation and the development of manufacturing industries.

Before the financial crisis in 2008, the Baltic countries pursued an economic strategy aimed at increasing GDP per capita by attracting foreign investment and fostering the banking sector. Following the economic downturn of 2008–2009, however, these countries were forced to shift their focus away from this economic model and towards exporting transport services and expanding maritime logistics. Cointegrating regression revealed a statistically significant correlation between GDP per capita and gross capital formation in Estonia and Lithuania,

Tab. 7: Cointegrating regression in the countries of the Baltic states (B3)

		Coefficient	Std. error	*T*-ratio	*p*-value
Estonia (EST)	Dependent variable: *GDPPCEST*				
	Const	18,057.700	13,199.600	1.368	0.188
	ULEST	−1,261.350	259.824	−4.855	0.000***
	GCFEST	−421.226	200.555	−2.100	0.050*
	EGSGDPEST	299.919	105.611	2.840	0.011**
	R-squared	0.760	–	–	–
	Durbin-Watson	0.700	–	–	–
Latvia (LVA)	Dependent variable: *GDPPCLVA*				
	Const	−5,576.590	9,254.220	−0.603	0.554
	ULLVA	−388.499	203.720	−1.907	0.073*
	GCFLVA	981.058	146.643	0.669	0.512
	EGSGDPLVA	370.772	790.427	4,691.000	0.000***
	R-squared	0.751	–	–	–
	Durbin-Watson	0.482	–	–	–
Lithuania (LTU)	Dependent variable: *GDPPCLTU*				
	Const	4,791.270	6,184.840	0.775	0.449
	ULLTU	−583.072	158.744	−3.673	0.002***
	GCFLTU	−288.465	152.739	−1.889	0.075*
	EGSGDPLTU	323.389	403.371	8.017	0.000***
	R-squared	0.886	–	–	–
	Durbin-Watson	1.011	–	–	–

Note: Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; *GDPPC* – GDP per capita (current USD); *UL* – labor force, total (% of total population); *GCF* – gross capital formation (% of GDP); *GCF* – exports of goods and services (% of GDP).

Source: Prepared using GDP per capita (current USD) World Bank national accounts data, and OECD National Accounts data files (2023); unemployment, total (% of total labor force) World Bank national accounts data, and OECD National Accounts data files (2023)

as well as a correlation between exports and GDP per capita in these countries (Tab. 7).

The Balkan region's model of economic growth (BA5) focused on the export of services, including the development of tourism. However, GDP per capita in these countries varied. Croatia achieved the highest figures for the 2000–2021 period. Montenegro and Serbia reached average figures, while Albania and North Macedonia showed lower figures. An analysis of the correlation between GDP per capita, employment rates, capital accumulation, and export of goods and services in these countries helps to explain these differences in the effectiveness of national economic reforms (Tab. 8).

Countries such as Albania and North Macedonia had excessive labor resources. Their national economies have failed to fully utilize this labor force in order to increase GDP and prioritize the development of specific areas of production or service. Meanwhile, other Balkan countries, such as Croatia and Montenegro,

Tab. 8: Cointegrating regression in the countries of the Balkan states (BA5) – Part 1

		Coefficient	Std. error	*T*-ratio	*p*-value
Albania (ALB)	Dependent variable: ***GDPPCALB***				
	Const	8,387.820	3,200.160	2.621	0.017**
	ULALB	−340.090	799.005	−4.256	0.001***
	GCFALB	−89.738	414.312	−2.166	0.044**
	EGSGDPALB	124.452	567.130	2.194	0.042**
	***R*-squared**	0.848	–	–	–
	Durbin-Watson	1.038	–	–	–
Croatia (HRV)	Dependent variable: ***GDPPCHRV***				
	Const	25,128.200	12,590.800	1.996	0.061*
	ULHRV	−730.752	253.740	−2.880	0.010***
	GCFHRV	−296.625	243.006	−1.221	0.238
	EGSGDPHRV	750.886	143.684	0.523	0.608
	***R*-squared**	0.478	–	–	–
	Durbin-Watson	0.310	–	–	–
Montenegro (MNE)	Dependent variable: ***GDPPCMNE***				
	Const	15,125.600	2,335.080	6.478	0.000***
	ULMNE	−438.042	401.850	−10.900	0.000***
	GCFMNE	−36.059	322.759	−1.117	0.279
	EGSGDPMNE	282.228	377.270	0.7481	0.464
	***R*-squared**	0.913	–	–	–
	Durbin-Watson	0.790	–	–	–
North Macedonia (MKD)	Dependent variable: ***GDPPCMKD***				
	Const	−4,636.740	1,773.420	−2.615	0.018**
	ULMKD	502.439	320.180	1.569	0.134
	GCFMKD	154.015	495.536	3.108	0.006***
	EGSGDPMKD	795.085	265.384	2.996	0.008***
	***R*-squared**	0.90184	–	–	–
	Durbin-Watson	1.218	–	–	–

Tab. 8: Cointegrating regression in the countries of the Balkan states (BA5) – Part 2

		Coefficient	Std. error	*T*-ratio	*p*-value
Serbia (SRB)	**Dependent variable: *GDPPCSRB***				
	Const	−2,682.090	1,732.190	−1.548	0.139
	ULSRB	601.909	590.682	1.019	0.322
	GCFSRB	140.933	680.868	2.070	0.053*
	EGSGDPSRB	129.275	236.855	5.458	0.000***
	***R*-squared**	0.752	–	–	–
	Durbin-Watson	0.642	–	–	–

Note: Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; *GDPPC* – GDP per capita (current USD); *UL* – labor force, total (% of total population); *GCF* – gross capital formation (% of GDP); *GCF* – exports of goods and services (% of GDP).

Source: Prepared using GDP per capita (current USD) World Bank national accounts data, and OECD National Accounts data files (2023); unemployment, total (% of total labor force) World Bank national accounts data, and OECD National Accounts data files (2023)

which have a more favorable geographical location, managed to harness their own labor resources in order to develop their tourism industry and increase GDP per capita.

The Central Asian region is characterized by a model of economic development that involves high levels of capital accumulation and the migration of surplus labor to neighboring countries. For instance, remittances from these migrant workers play a pivotal role in the economy of Tajikistan, Uzbekistan, and the Kyrgyz Republic. Nevertheless, this economic model has led to the lowest GDP per capita among these countries compared to other countries with transitional economies. Kazakhstan stands out from this trend. The country has achieved higher GDP per capita through the accumulation of capital, efficient use of labor, and development of its extractive industries. These differences can be explained through the use of cointegrating regression (Tab. 9).

A comparative analysis of data from the studied countries reveals that there is not a universal economic model for successful transition of post-Soviet states to a market economy. However, several factors play a critical role in this process, including the development of export-oriented industries, efficient utilization of domestic labor, attraction of migrant labor, capital accumulation, and the size of the national economy. In the Visegrad Group (V4) countries, a model of a social market economy with a strong manufacturing sector has been established. The Baltic (B3) and Balkan (BA5) states have predominantly adopted a post-industrial, service-oriented economic model. Central Asian (CA4) nations have opted for a paternalistic economic model that relies on raw material extraction and agriculture.

The prospects for economic growth in the countries of the Visegrad Group (V4), the Baltic states (B3), Central Asia (CA4), and the Balkan states (BA5), including Kazakhstan, following the COVID-19 pandemic, largely depend on the choice of the future course of state economic policy. It is crucial to gradually move away from the model of "dependent capitalism" and reliance on remittances from migrant labor towards the development of the national economy and domestic market. One of the key instruments of this policy should be the creation of new jobs and the reduction of unemployment rates. Global practice demonstrates that increasing the share of the national economy in the world economy and gross capital formation in the GDP structure is a strategic tool of state economic and scientific-technical policy.

As the experience of V4 and B3 countries shows, an increase in the level of wages can be achieved only with the growth of labor productivity. It is achievable with a radical transformation of the model of socio-economic development, focused on the formation and development of the innovation economy.

Tab. 9: Cointegrating regression in the countries of the Central Asia (CA4)

		Coefficient	Std. error	*T*-ratio	*p*-value
Kazakhstan (KAZ)	**Dependent variable: *GDPPCKAZ***				
	Const	24,187.000	3,341.660	7.238	0.000***
	ULKAZ	−1,937.350	245.318	−7.897	0.000***
	GCFKAZ	−277.495	104.151	−2.664	0.016**
	EGSGDPKAZ	905.187	614.379	1.473	0.158
	***R*-squared**	0.852	–	–	–
	Durbin-Watson	0.825	–	–	–
Kyrgyz Republic (KGZ)	**Dependent variable: *GDPPCKGZ***				
	Const	−1,001.700	183.246	−5.466	0.000***
	ULKGZ	290.070	375.191	7.731	0.000***
	GCFKGZ	272.438	348.834	7.810	0.000***
	EGSGDPKGZ	686.117	307.060	2.234	0.038**
	***R*-squared**	0.949	–	–	–
	Durbin-Watson	1.404	–	–	–
Tajikistan (TJK)	**Dependent variable: *GDPPCTJK***				
	Const	1,327.400	265.133	5.007	0.000***
	ULTJK	−24.744	197.260	−1.254	0.226
	GCFTJK	−2.292	424.243	−0.540	0.596
	EGSGDPTJK	−10.591	191.324	−5.536	0.000***
	***R*-squared**	0.932	–	–	–
	Durbin-Watson	1.079	–	–	–
Uzbekistan (UZB)	**Dependent variable: *GDPPCUZB***				
	Const	4,739.300	365.099	12.980	0.000***
	ULUZB	−199.218	224.894	−8.858	0.000***
	GCFUZB	−8.465	883.073	−0.959	0.351
	EGSGDPUZB	−64.443	416.383	−15.480	0.000***
	***R*-squared**	0.964	–	–	–
	Durbin-Watson	2.028	–	–	–

Note: Significance levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; *GDPPC* – GDP per capita (current USD); *UL* – labor force, total (% of total population); *GCF* – gross capital formation (% of GDP); *GCF* – exports of goods and services (% of GDP).

Source: Prepared using GDP per capita (current USD) World Bank national accounts data, and OECD National Accounts data files (2023); unemployment, total (% of total labor force) World Bank national accounts data, and OECD National Accounts data files (2023)

3.2 Discussion

This study suggests that the prevailing approach, which has characterized many Central and Eastern European (CEE) countries and a significant portion of the post-Soviet space as being in an ambiguous transitional position in Europe, requires a fresh reevaluation. There is partial agreement with the perception that CEE countries, which have previously joined the EU, are often seen as lagging in terms of their democratic culture and liberal principles. In a sense, they have been in a constant state of transition for over three decades, attempting to catch up with their more advanced Western counterparts. Nonetheless, certain countries within this context have made notable advancements in addressing these issues (Dunajeva & Górak-Sosnowska, 2023). Despite the marked progress achieved through economic reforms in the Eastern and Western parts of Europe, a persistent disparity persists in the financial, economic, and socio-economic conditions that shape the day-to-day lives of citizens (Bartha & Valuch, 2024).

Simultaneously, a similar understanding of the nature of the challenges present within the post-Soviet space has emerged. As a result of structural imbalances inherited from the Soviet economy and the sluggish pace of economic and institutional reforms, the countries of the former Soviet Union endured a prolonged and profound production decline during the 1990s (Dabrowski, 2022).

In analyzing this issue, many researchers question why the transformation of post-socialist societies did not yield the expected outcomes and whether neoliberal capitalism was the only viable path for development in Eastern Europe following the collapse of the socialist experiment. According to the prevailing view, the solution lies in demonstrating that an alternative model is possible: one characterized by greater egalitarianism, democracy, and the rule of law. However, this socio-political alternative must simultaneously contend with two contemporary powerful forces: neoliberal capitalism and nationalist populism (Żuk & Toporowski, 2020).

To understand the differences in institutional development in transition countries, Eydam and Gabriadze (2020) examined the role of pre-Soviet institutional experience in institution-building after the collapse of the Soviet Union. An index was used to measure institutional experience, which reflects previous experience with independent non-Soviet institutions. Cross-analysis has shown that institutional experience is statistically significantly associated with the quality of political, administrative, and legal institutions in modern transitional economies.

A significant number of works are devoted to the development of B3 countries, most of which also positively assess the results of their economies' transformation. At the same time, there are also negative opinions of some authors on this issue. However, one can hardly agree in general with the statement that GDP growth in B3 countries, mainly due to large-scale credit expansion and increased subsidization of certain industries, objectively does not contribute to the socioeconomic development of the Baltic states (Olenchenko, 2017). V4 and B3 countries over the last ten-year period have generally continued to show positive dynamics in their economic development indicators. Despite some fluctuations in individual indicators, by most criteria, they are close to the level of the EU and OECD countries. At the same time, they show more dynamic growth than the EU or the OECD as a whole (OECD, 2020). However, B3 countries still lag behind the EU's best performers in GDP per capita, labor productivity, wages, and other criteria.

In this connection, dependent market capitalism and the analysis of its comparative advantages and disadvantages and the risks of losing economic independence are of theoretical and methodological importance. According to Nölke and Vliegenthart (2009), this model of development provides certain prospects, which is demonstrated by the successes of the V4 and B3 countries.

The latter is also recognized by other researchers. For example, Chetverikova (2020) points out that many authors evaluate the V4 countries' membership in the EU as successful, which is confirmed by the improvement of these countries' positions in various international rankings. During the period of their membership in the European Union, their economic position has strengthened and the combined GDP of Hungary, Poland, Slovakia, and Czech Republic has more than doubled over the past 16 years, coming close to EUR 1 trillion.

The reports of the Institute of Europe of the Russian Academy of Sciences also state that the accession of the V4 countries to the EU was one of the factors of their accelerated economic development, but it also shows their

weaknesses, in particular the fact that the model of economic growth was based on cheap labor. Now, further growth is possible only with the transition to a knowledge-based economy, and the growth of the share of knowledge-intensive industries (Kondratiev, 2016; Sachs & Warner, 1995; Shishelina, 2017).

The achievements of Central and Eastern European countries in reducing economic disparities with Western Europe, raising the technological level of production, and significantly increasing regional gross income through enhanced labor productivity, as well as specific challenges, must be duly considered in the reform of Kazakhstan's economy. When reforming Kazakhstan's economy, it is imperative to draw lessons from the experiences of Central and Eastern European countries, particularly their achievements in narrowing the economic gap with Western Europe, advancing the technological level of production, and increasing regional gross income through improved labor productivity, while also acknowledging the challenges encountered during their transition processes. The fundamental work of the Institute of Economics of the Russian Academy of Sciences also recognizes the success of the countries of Central and Eastern Europe in reducing their economic lag from Western Europe, increasing the technological level of production, and a significant increase in the regional gross product by increasing labor productivity. At the same time, the level of unemployment has fallen to the average level and is lower than the similar indicator in the EU as a whole. Along with the successes, the authors have analyzed in detail the serious problems of Central-Eastern Europe, which should certainly be taken into account in reforming the economy of Kazakhstan (Glinkina, 2017).

A sufficient number of studies, including those by reputable international organizations, in particular the OECD and the World Bank Group, are devoted to the problems of Kazakhstan's development. Thus, the OECD study concludes that Kazakhstan strives to get into the top 30 countries of the world by 2050, but this requires achieving high rates of growth, to solve a number of serious structural problems (OECD, 2020; World Bank Group, 2018). The study rightly suggests that resource dependence has begun to create a number of macroeconomic problems, in particular, the economy of Kazakhstan has become similar to other less diversified economic systems in many aspects (OECD, 2020).

A World Bank study (Lashitew et al., 2020) found that efforts to improve economic diversification have not always been accompanied by improvements in competitiveness, especially among extremely resource-rich countries (WeForum, 2019). Other relatively successful examples of diversification include countries such as Chile, Norway, and to some extent Malaysia which has improved their competitive capabilities in most areas of activity. The Oman case study showed that real diversification remains elusive for one extremely resource-dependent oil-producing country. Despite the rapid expansion of production on a small base that has grown the fastest, this country is still heavily dependent on oil revenues, and production (including refined oil, gas, and minerals) is only 10% of GDP (Lashitew et al., 2020; World Bank Group, 2020).

Conclusions

During the analyzed period of 2000–2021, the average annual economic growth reached its highest level in Kazakhstan in 2001 at 13.5%, in Croatia in 2021 at 13.1%, as well as in Montenegro in 2021 at 12.4%, Latvia in 2006 at 12.0%, Lithuania in 2007 at 11.1%, and Tajikistan in 2003 at 11%. The most significant economic contraction was observed in Montenegro in 2020, where this indicator reached its lowest value of −15.3%, as well as in Estonia, Latvia, and Lithuania in 2009, with respective declines of −14.6%, −14.3%, and −14.8%.

It was found that in the pre-crisis period (2000–2007), GDP growth in all of the countries under consideration was significantly higher than in the post-crisis period (2010–2019). For all the countries taken for comparison, the average annual GDP growth rate in the pre-crisis period was significantly higher than that of the OECD group as a whole. This is explained by the fact that the post-socialist economies in the period 2000–2007, thanks to investments by transnational companies, the transfer of separate assembly production, as well as significant financial support from the EU and access to its markets, were able to recover faster after the crisis of the early 90s due to the collapse of the socialist system. A study of economic growth trends during the global financial crisis of 2008–2009 showed that almost all countries experienced a decline in GDP growth, only

Poland successfully survived the crisis, and GDP growth rates in Kazakhstan fell sharply almost 5 times.

The average GDP per capita in the Czech Republic from 2015 to 2021 exceeded the global average by a factor of 2, in Slovakia by almost 1.7 times, in Hungary by 1.4 times, and in Poland by 1.3 times. Among the Baltic countries, Estonia had the highest indicator, surpassing the global average by a factor of 2, while Latvia and Lithuania exceeded it by 1.7 times. In Central Asia, the highest indicator was observed in Kazakhstan, and in the Balkans, it was in Croatia.

Following the COVID-19 pandemic, the economic development of these countries will be determined by the effectiveness of the corresponding state economic policies. For the majority of these nations, gradually moving away from the "dependent capitalism" model and reducing their reliance on remittances from labor migrants in favor of developing their national economies and domestic markets is of utmost importance. At present, many countries with transitional economies, including Kazakhstan, are striving to approach the characteristics of the developed economies, but with the current model of economic development, it is unlikely to overcome significant differences between them. One should also take into account the fact that the developed economies and neighboring China are switching to new energy-saving and "green" technologies. Today, there is a clear trend of declining oil demand and price, which seriously threatens Kazakhstan's economy. Other Central Asian countries maintain a paternalistic economic system, which hinders economic growth due to limited resources. In the Balkan countries, a lack of institutional reform is the main impediment to investment and economic modernization. Population decline is a serious challenge for the Baltic states. The Visegrad Group is highly reliant on the economic conditions of the EU and CIS markets.

At the current juncture of global competition, many countries with transitional economies still retain sufficient resources to make a decisive shift toward a new model of economic growth. The priorities of this transformation should center on creating an efficient economic framework grounded in innovation and high-tech industries, alongside the simultaneous and accelerated development of human capital. These and other initiatives will serve as catalysts for sustained economic expansion and enhanced living standards similar to those observed in developed nations.

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What is the level of spatial autocorrelation of the green economy? The case study of voivodships in Poland

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Abstract: *In an era of resource scarcity, climate change, and environmental degradation, the growth of a green economy necessitates a new course for socio-economic development that successfully pursues sustainable development objectives. Among other things, variables related to demographics, the environment, technology, the economy, and society all contribute to its polarisation. The aim of the study is to understand what factors influence the development of the green economy in the various provinces of Poland, and how these factors may be related to each other in a spatial context. The selection of factors from 2010 to 2020 was the availability of Statistics Poland records. The study offers a spatial analysis of Poland's green economy in its provinces in 2010, 2019, and 2020. Spatial autocorrelation was found using spatial statistical methods, and the geographical pattern of the green economy's formation was shown. These analyses used measures of spatial autocorrelation, which allowed for the identification of spatial relationships of a particular characteristic throughout the whole research region and the connection between a particular place and nearby locations. Due to a combination of natural and geographic features, as well as the impact of socio-economic factors, each province in the nation has a unique economic climate, which determines its level of development and standard of life.*

Keywords: *Green economy, spatial differentiation, province, spatial autocorrelation measure, local Moran's coefficient, global Moran's coefficient, synthetic measure.*

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Introduction

The term "green economy" (GE) is a multifaceted idea encompassing financial, social, and infrastructure components. A significant challenge that will undoubtedly impact practically every economic sector is the shift from a traditional to a green economy (industry, trade, agriculture, tourism). A green economy (GE) prioritizes environmental health and quality of life over financial development and economic growth. In fact, it may even be said that these factors are marginally more essential. The shift from the conventional brown economy to the green economy will be a gradual, intricate, and transformative procedure (Kasztelan, 2017; Naik, 2021). The region has a number of difficulties, including enhancing resource efficiency, advancing low-carbon technology, cutting gas emissions, raising investment in the preservation of natural capital, and lowering economic

inequality (Halle, 2011). The environmental, economic, and social justifications for the shift to an eco-friendly economy are well established. Environmental harm, declining air quality, rising greenhouse gas emissions, and declining water quality are all consequences of rapid economic expansion. Sustainable development is hampered by these environmental issues (Yi & Liu, 2015).

The transition from a linear to a closed-loop economy is being driven by the depletion of primary resources and the implications this has for the environment. Since closed-loop systems are thought to offer significant potential to save primary resources, safeguard biodiversity, and slow down global warming, CE is viewed as a sustainable development concept (Luthin et al., 2023). Sustainable development faces significant obstacles from the efficient use of mineral resources, their depletion, and the escalating effects of climate change. As mentioned by Hu and Gu (2024), simultaneously, the increasing impacts of climate change, exhibited by extreme weather events and ecological disruption, highlight the pressing necessity of a significant transition towards a sustainable economy, also known as the green economy.

The green economy lowers environmental dangers, promotes social justice, and increases prosperity. It incorporates goals that can be pursued by both local and national governments, including social, economic, and environmental ones. An economy that relies on fossil fuels for transportation, energy production, and production is known as a "brown economy." Natural resources give regions the raw materials they require for industry and energy generation, the cornerstone of economic progress. There are detrimental environmental effects from their extraction, processing, and use, such as greenhouse gas emissions, forest loss, and water contamination (Akalibey et al., 2023).

The polarisation of green circular economy (CE) development across regions can be attributed to geographical location, level of economic development, and resource distribution. Geographical factors significantly shape the industrial structures of regions (Di et al., 2023). A region with few natural resources is more likely to form CE due to minimised consumption of natural resources (Robaina et al., 2020). As a consequence of economic activity, economic growth erodes natural capital. Green growth is important for both economic development and environmental improvement (Xu et al., 2022). Churski et al. (2021) highlight the importance of reconsidering the definition and use of regional development determinants in connection to socio-economic development processes, particularly those involving the growth of the green economy.

Local actors implement GE policy. Most research on GE focuses on the industry level or national scale. Regional aspects of GE are still under-researched. The article's significance derives from its research findings on GE at the provincial level in Poland, covering the period from 2010 to 2020. The aim of the study is to understand what factors influence the development of the green economy in the different provinces of Poland, and how these factors may be related to each other in a spatial context. Analyzing the context of spatial autocorrelation allows us to better understand the degree of polarization among provinces and how differences among regions in the adoption of green economy principles may be related to their geographic proximity and specific local characteristics. The study used a variety of analysis methods, including a literature review, descriptive statistics and a synthetic measure to assess the overall degree of green economy adoption in each province. In addition, a measure of spatial autocorrelation was used, which made it possible to assess whether the development of the green economy in one region is related to development in neighboring areas. The authors proposed the following research questions to clarify regional differences in the green economy (GE) and better understand its regional aspects: What elements influence the development of the green economy? Which are the main and most important determinants of GE? What is the link between GE environment, health care and waste management spending, energy consumption and production, natural resource management and waste management and its level? What impact will the growth of the green economy have on the local economy?

In this study, Poland is chosen as a case due to its unique combination of rapid economic growth, reliance on coal, and significant regional disparities, all of which present distinctive challenges and opportunities in the shift toward a green economy. Unlike many other EU member states, Poland's energy mix remains heavily

dependent on coal, making the green economy transition more complex but highly relevant in the context of EU climate targets. Additionally, Poland's regional diversity (spanning from highly industrialized areas to predominantly rural regions) provides a rich landscape for examining spatial variations in green economy initiatives. The availability of detailed regional data from 2010 to 2020 further allows for a robust analysis, contributing to the broader understanding of how EU environmental strategies can be effectively tailored to member states with unique economic and energy profiles.

The originality of the article lies in its interdisciplinary approach, combining environmental, social, and economic variables, and the use of analytical methods in the analysis of the development of the green economy (synthetic measure, TOPSIS, and spatial autocorrelation). In addition, the originality lies in the study of specific regions (peripheral areas of the EU, voivodeships in Poland), which allows new conclusions to be drawn about local green economy initiatives. All these elements make the article contribute important conclusions to the scientific discourse, especially in the context of contemporary challenges related to the green economy and the assessment of progress in the green transition, by creating a synthetic indicator and identifying regions that need more support in the transition to the green economy, taking into account regional spatial dependencies.

1 Theoretical background

The transformation of the economy to a green growth path requires changes in the areas of competence, development, innovation, social awareness, and the natural environment. In fact, environmental protection has the potential to improve the process of sustainable development as well as the modernisation of a region, amongst other things. Society, the environment and the economy form a network of interconnectedness (Zaucha, 2012). The region-specific dimension of GE processes is based on spheres that are endowed with individual development dynamics and manifest their multidimensionality in the economic, cultural, social and environmental spheres, among others.

According to studies conducted by Myrdal (1957) and Perroux (1955), the degree of development in each region affects how desirable it is to the other. Von Stackelberg and Hahne (1998) indicate that economic growth occurs unevenly and is centered in areas referred to as geographical growth centers. The concentration of population, production, and service potential is correlated with the degree of polarization in a given location. Furthermore, as Gawlikowska-Hueckel (2005) notes, the degree of urbanization and the composition of the economic system also influence the absorption of polarization impulses.

The political backing, resource distribution, economic development level, and geographic location all contribute to significant spatial differences in GE development between geographical locations. Geographical variables play a major role in shaping the industrial structures of different regions, which leads to discernible variations in carbon emissions across them. Di et al. (2023) findings state that circular economy encourages material recycling and resource efficiency as a sustainable means of managing resources, reducing waste production, and bolstering renewable energy sources.

According to Akalibey et al. (2023), one crucial instrument for attaining sustainable development is the shift of economies from a brown to a green economy. The green economy lowers environmental hazards, promotes social justice, and enhances well-being. It combines goals that can be pursued by the business sector, local, regional, or federal governments, and the social and environmental domains. As stated by Murray (2017), building a green economy entails addressing environmental issues in addition to guaranteeing social stability, economic security, and the creation of new opportunities for sustainable growth. GE's basic tenet is that resources are obtained by other organizations through the recycling process of wasted materials. Reducing, reusing, recycling, and recovering are the "4Rs" that are associated with the green economy. These speak of lowering resource usage, protecting natural capital, and recovering resources. In line with Elimam's (2017) research, this enhances the quality of life for locals and boosts the region's economy by offering more efficient methods to use resources, reducing environmental pollution, and encouraging green growth. It appears to point to a sharing economy as well. The comprehensive use of resources and sustainable management are the main goals of waste management.

Ralph (2021) points out that the linear economic model has resulted in pollution and the wasteful exploitation of natural resources. Utilizing recyclable materials again is a component of the circular economy (CE). Moreover, as Kirchherr et al. (2017) point out, CE has emerged as a primary tactic for resolving environmental issues. While CE's consequences on the environment have received a lot of attention, its effects on the economy and society have received less attention. Decision-makers at the national, regional, and municipal levels are increasingly focusing on CE as a key component of a sustainable economy (OECD, 2020). Mhatre et al. (2021) state that the goals of CE are to reduce resource consumption and the resulting environmental impact, as well as to maximize material efficiency.

According to the research study by Prieto-Sandoval et al. (2018), the term circular economy represents a sustainable development paradigm. It encourages waste reduction, closed-loop systems, and resource efficiency to reduce environmental effects while advancing the development process.

Promoting economic growth and development, as indicated by Fan and Wang (2024), while preserving the ecosystems and resources necessary for humanity's survival is known as green growth. Reducing the amount of material extracted from the environment is necessary to preserve the environment while reaping its benefits. To achieve this, we must change the way we consume and produce goods and services. Our economy must be greened. A green economy is one that cares about the environment and the welfare of society when choosing goods and services (Fan & Wang, 2024). According to Stoian et al. (2023), sustainability objectives, like those of a green economy, must take into account the opportunity costs of decisions, as well as the short- and long-term positive externalities. The intricate interplay among the environment, society, and economics gives rise to all of these factors.

Given the environmental, social, and economic aspects of green infrastructure, the green economy is a sustainable economy. Declining air quality, depopulation (suburbanization process, aging population), poverty, and unemployment, poorer growth in entrepreneurship, substantial spatial (intra-regional) divergence of regions, strong growth in trash, and capital leaching are its key issues for regions. These processes have the potential to drastically deteriorate the environment, alter the demographic makeup, and make certain areas less desirable. It is a route for economic growth that will be feasible in a sustainable manner while keeping environmental requirements and limitations in mind. Sustainable development can be accomplished with its help (Khoshnava et al., 2019).

The Green New Deal and the green economy are related. Its concept entails incorporating environmental considerations into strategies for social and economic rehabilitation following the financial crisis. Integrating social and economic inequality with climate change into national, regional, and local public policy was the goal of the Green Deal's policies and policy instruments. The European Green Deal intends to make the EU a modern, resource-efficient, and competitive economy while addressing the problems caused by climate change and environmental deterioration (Rivas et al., 2021).

Natural capital, entrepreneurship, and environmental quality of life should all be areas that are regularly evaluated under GE (OECD, 2014). It is important to track social aspects of the environment or economy in terms of GE, as well as the interaction between the two (OECD, 2011). None of the indicators provided by UNEP (United Nations Environment Programme) are chosen at random. It suggests an approach for developing systems of these indicators, presuming that nations (or regions) ought to develop a set of assessment indicators in accordance with their unique circumstances (environmental, social, and economic) (UNEP, 2012).

A set of metrics was put up by Broniewicz et al. (2022) to evaluate legislation in terms of the needs for climate change adaptation (and consequently, adjustments in the shift to a green economy). A set of metrics focused on natural capital, governmental policies promoting the green economy, and socio-economic challenges were identified by Ryszawska (2013). Forest area, protected areas, energy productivity, energy consumption, the production of non-renewable energy, trash recycling, spending on environmental development and broadcasting, environmental innovation, employment, and policy instruments are a few examples of indicators.

The shift to a green economy is an unavoidable path for development, necessitating greater

efforts to advance the growth of the green economies at the local, regional, and national levels. Individual economies' capacities and national interests must be considered. In terms of geography it refers to the efforts made to improve living circumstances, lessen the environmental impact on local and regional systems, and increase competitiveness on both fronts (Hahnel, 2010). As indicated by Herodowicz (2018), the green economy influences economic growth and helps the area meet environmental and climate goals. As noted by Lorek and Spangenberg (2014), this notion is incompatible with the requirements of a regionally balanced development.

Although several studies have analyzed the green economy at national scales in Western Europe (e.g., Germany, Italy), few have addressed the spatial differentiation of green economy measures in post-communist, coal-reliant countries like Poland. This research fills that gap by offering a detailed analysis of regional disparities, applying spatial autocorrelation to explore the unique challenges Poland faces in transitioning toward a sustainable economy. Atalay and Akand (2023) performed spatial analysis using LISA (Local Indicators of Spatial Association) and examined green economy indicators across OECD countries. The research highlighted the spatial relationships between economic growth and environmental pollution, providing a useful comparative framework for analyzing similar patterns in Poland. Including this research could demonstrate how our study adds unique insights into green economy transitions in a post-communist country like Poland, which is heavily reliant on coal compared to other OECD nations. Qin et al. (2024) analyzed the interactive response between green finance and productivity using spatial autocorrelation, providing a foundation to compare how financial mechanisms influence green economy transitions across different regions. This would be relevant for demonstrating how your study focuses more on spatial disparities within a coal-reliant economy, which differs from the financial and industrial context of China. This study explores the spatial interaction between green finance and productivity across Chinese provinces using spatial econometric techniques. It highlights regional differences and provides insights on how local economic policies can influence green productivity. The study identifies gaps in understanding how green finance impacts different regional economies, offering a valuable comparison with your research on Poland's green economy. Zhou et al. (2023) explore the relationship between renewable energy deployment and green economic growth, utilizing spatial regression techniques to assess regional spillover effects. They highlight gaps in renewable energy policies' effects on green growth across different regions, which could be relevant to our analysis of spatial patterns in Poland's energy-dependent regions.

The concept of a green economy encompasses a multitude of dimensions pertaining to sustainable development. It is this very multidimensionality that is pivotal to the realisation of sustainable, long-term socio-economic development. Poland, with its diverse economic, ecological and social structure, offers a wide range of conditions that can affect the effectiveness of green economy implementation in different regions. The selection of provinces allows for the examination of these differences and a more nuanced understanding of the regional specifics that determine the effectiveness of green activities. These variations encompass a range of factors, including the diverse natural resources that inform environmental policy, as well as local challenges related to industry, agriculture, or water management. Poland is distinguished by significant disparities in economic, social, and environmental development across its provinces. Different regions exhibit varying degrees of natural resource endowment, infrastructure, environmental policy, and industrial development. The analysis of the voivodeships enables the identification of these differences and an understanding of their impact on the implementation of green economy principles. By undertaking an analysis of individual provinces, it is possible to make the necessary adjustments to green activities in order to meet the specific needs of the region. The natural resources available in each of Poland's provinces exert a significant influence on the development of the country's green economy. For instance, provinces with a high proportion of forest cover (such as the Podlaskie and Lubuskie voivodeships) may prioritise the protection of biodiversity, whereas agricultural regions (such as the Wielkopolskie and Mazowieckie voivodeships) may focus on the development of sustainable agricultural practices. The selection of provinces permits a comprehensive examination of the utilisation

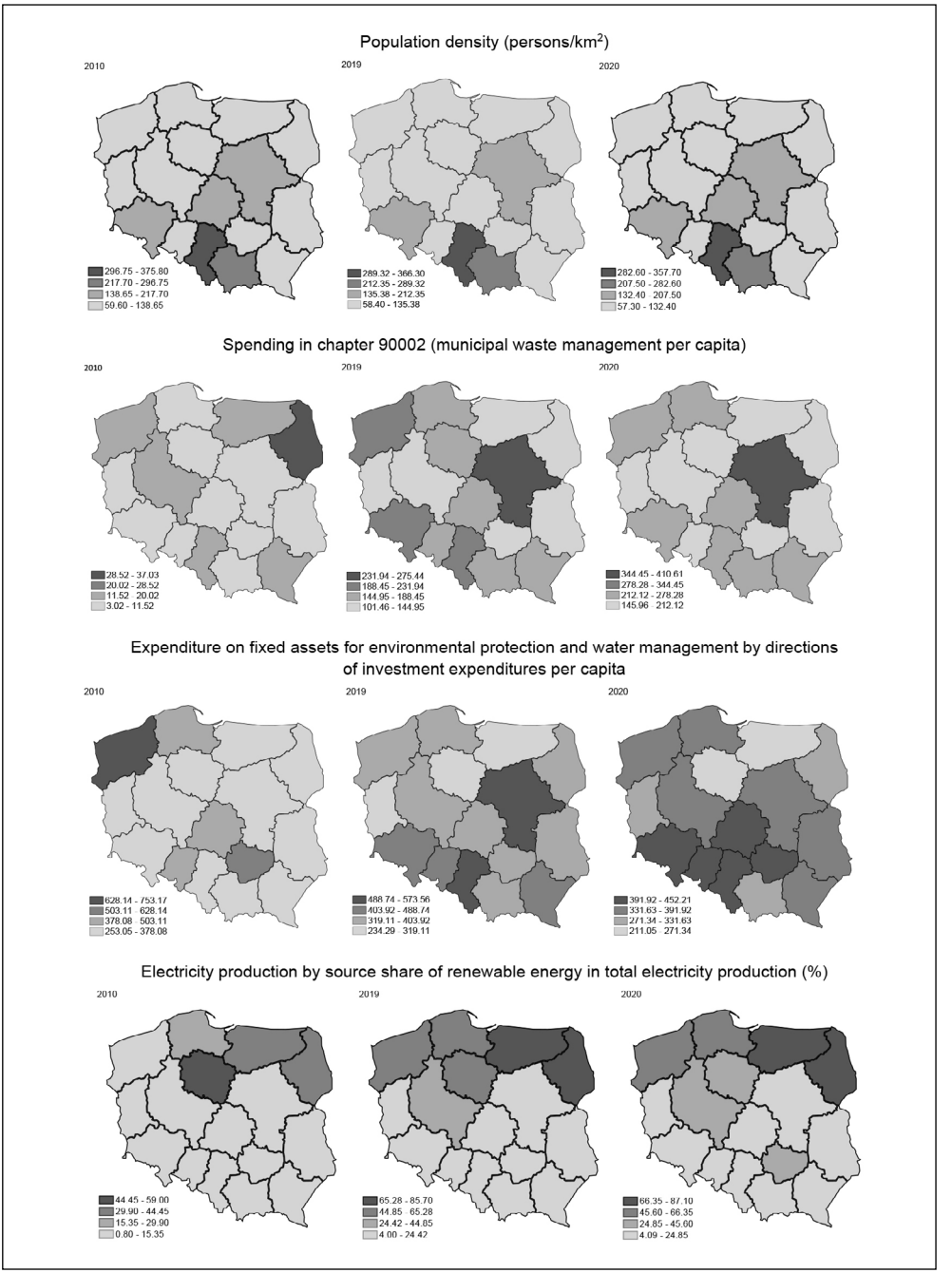

Fig. 1: **The specifics of Poland's voivodeships selected variables – Part 1**

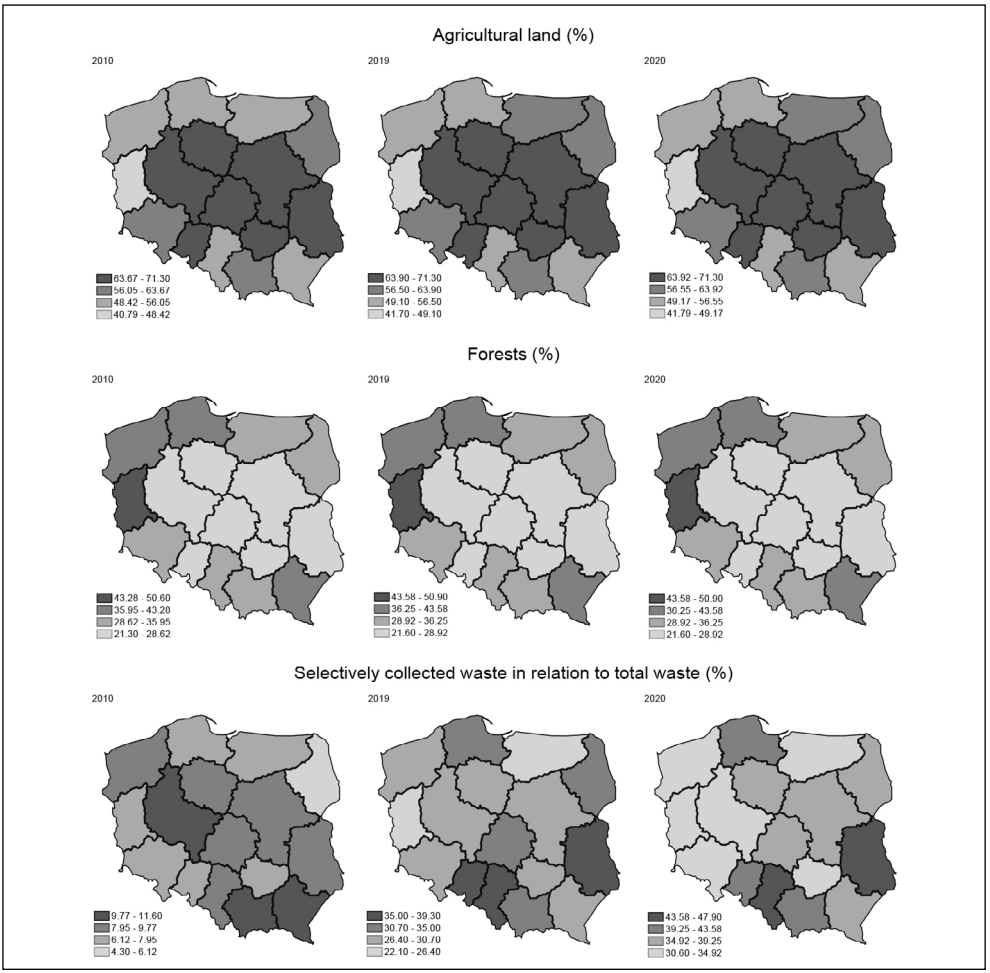

Fig. 1: The specifics of Poland's voivodeships selected variables – Part 2

Source: own (based on data from Statistics Poland)

of these resources in the context of the green economy (Fig. 1). This approach also facilitates a more nuanced comprehension of the interrelationships between regional ecological and economic processes, which can inform the development of efficacious green growth policies in the future.

The population density of Poland between 2010 and 2020 was characterised by a general trend of decline, with the exception of a few provinces (e.g., Małopolskie and Mazowieckie), where an increase was observed. These trends can be attributed to a combination of migration processes and demographic changes. The Polish population is characterised by an ageing demographic and a low birth rate, which has an adverse effect on population stability. An analysis of municipal waste management expenditures (in PLN per capita) in Poland from 2010 to 2020 reveals a trend of increasing waste management expenditures. This may be attributed to a growing population and rising costs associated with waste segregation, processing and landfilling. There is evidence

of an increase in investment in environmental protection between the years 2010 and 2020. However, a slight decrease is observed in 2020 in comparison to 2019. Regional disparities indicate elevated expenditure in more developed provinces, including Silesia, Mazovia and Lower Silesia, as well as in provinces that have historically allocated significant resources to infrastructure development, such as West Pomerania. In provinces with lower outlays, such as Warmian-Masurian and Kuyavian-Pomeranian, the decline in investment may be indicative of a reduction in environmental priorities. The majority of provinces demonstrated an increase in the proportion of renewable energy sources (RES) utilized in electricity generation between 2010 and 2020. The proportion of forest cover in Poland is gradually increasing as a consequence of sustainable development, afforestation and environmental protection initiatives. The provinces of Lubuskie, Podkarpackie and Pomorskie are characterised by a high proportion of forest cover, whereas other forms of land use, including agriculture, are more prevalent in Łódź and Kujawsko-Pomorskie. An analysis of data on the selective collection of waste in relation to the total volume of waste generated in Poland between 2010 and 2020 reveals a notable increase in the efficiency of selective waste collection. This suggests that Poland's waste management systems have undergone a positive transformation, reflecting a growing environmental awareness among the general public. In conclusion, the upward trajectory of selective waste collection in Poland is a favourable development and represents a significant stride towards sustainable resource management (Fig. 1).

In Poland, as in other countries within the European Union, there is an emerging trend towards the implementation of measures designed to advance environmental protection, sustainable development and the efficient management of resources. Consequently, the examination of the extent to which a green economy is being pursued at the provincial level represents a valuable instrument for the identification of regions that have attained a superior level of sustainable development and those that necessitate further assistance in this regard. In this context, an investigation into the spatial autocorrelation of the green economy in Poland's provinces will facilitate the formulation of conclusions regarding the spatial mechanisms influencing sustainable development and the identification of factors that can be employed to enhance regional policies.

The authors set forth the following hypotheses:

H1: There is positive spatial autocorrelation of green economy indicators across regions in Poland, indicating that regions with high green economy performance group together.

H2: Provinces with historically high dependence on coal show lower green economy growth rates compared to others.

H3: Health care spending and waste management spending have a positive autocorrelation, indicating that these two areas have a reciprocal effect on green economy growth.

2 Research methodology

The process of creating the synthetic measure – the green economy, which uses as the foundation for evaluating, involves the following steps: choosing the diagnostic variables and the study area; normalizing the variables using a zero-based unitization method; creating the synthetic measure using the chosen aggregation formula (TOPSIS method); linearly ordering the objects; and extracting typological classes for the entire synthetic measure's variation area (by analyzing spatial autocorrelation, correlation coefficient, bag diagram, and maps of spatial differentiation).

The empirical data was gathered between 2010 and 2020, with a focus on Poland's 16 voivodeships, from a spatial perspective (as a periphery territory of the EU). A voivodeship is the highest level of the country's basic geographical division and is a unit of local government, i.e., a regional self-government community (all residents), established to carry out public administration functions.

The choice of 2010, 2019 and 2020 was dictated by several factors related to the availability of data within official statistics and evolving socio-economic conditions. The year 2010 was chosen as a baseline because it represents a period of economic stabilization following the global financial crisis, making it an appropriate starting point for the analysis of trends in the green economy. The year 2019 was chosen to represent the most recent period prior to the pandemic, thus capturing the state of the green economy prior to the significant disruption caused by COVID-19. The year 2020 was included to assess the direct impact of the pandemic on the transformation

of the green economy, as it had a unique and profound impact on economic and environmental processes worldwide. Intermediate years were omitted mainly due to inconsistencies and gaps in data availability for some variables in official statistics. The years selected are intended to provide a clear and comparable picture of the main economic and environmental developments while recognizing the limitations of data comparability and changing legislation.

In analyzing the performance of the voivodeships, it is important to take into account the social, economic, and environmental determinants of endogenous potential. There is an interplay between the determinants of the green economy. The determinants are a group of interdependent phenomena occurring simultaneously within the same area. The selection of the twelve variables is based on previous research that demonstrates their relevance to sustainability and the green economy. Healthcare investments have been proven to cause environmental damage through emissions but also promote sustainability indirectly by improving public health (Berniak-Woźny & Rataj, 2023). Expenditures on waste management are essential in enabling waste reduction and recycling, which are essential elements for reducing the environmental footprint (Patwary et al., 2024). Fixed asset expenditure on environmental protection and water management plays a crucial role in controlling CO_2 emissions and water conservation, fostering green economic development (Rivas et al., 2021). Electricity consumption in rural areas, especially the reliance on non-renewable sources of energy, affects environmental performance, while clean energy adoption supports sustainability. Electricity generation and renewable energy generation constitute the essence of environmental sustainability, with the former reducing emissions and facilitating sustainable development (Robaina et al., 2020). The proportion of agricultural land to total area is important as sustainable agriculture has a positive impact on environmental and economic performance (Berniak-Woźny & Rataj, 2023). Proportion of forests in total area facilitates carbon sequestration and habitat for biodiversity, improving environmental performance (Rivas et al., 2021). Legally protected areas play an important role in biodiversity conservation and mitigate human influence. The ratio of ecological species enables long-term environmental health through biodiversity, whereas the lowering of the percentage of operating landfills mitigates emissions and pollution (Patwary et al., 2024). Lastly, selective waste collection

Tab. 1: A list of variables that characterize the green economy

Variable number	Variables	Unit
X_1	*Expenditure on healthcare*	PLN/pc
X_2	*Spending on waste management*	1,000 PLN/pc
X_3	*Expenditure on fixed assets for environmental protection and water management*	PLN/pc
X_4	*Electricity usage in rural areas*	kWh/pc
X_5	*Overall electricity generation*	GWh/pc
X_6	*Electricity production from renewable sources*	GWh/pc
X_7	*Proportion of agricultural land in total area*	%
X_8	*Proportion of forests in the total area*	%
X_9	*Proportion of legally protected areas in the total area*	%
X_{10}	*Proportion of ecological species in the total area*	%
X_{11}	*Proportion of active landfills in the total area*	%
X_{12}	*Proportion of selectively collected waste in total waste*	%

Source of data: own (based on the Statistics Poland (stat.gov.pl))

enhances recycling and restricts environmental effects, and it is linked directly to waste management performance (Stoian et al., 2023). These factors are backed by empirical studies and are central to the examination of the green economy and sustainability.

These factors constitute a complex web of interconnected variables that form a multidimensional space. In the investigation, the variables listed in Tab. 1 were differentiated. Additionally, Tab. 2 depicts the descriptive statistics of these variables. Each of the selected variables plays a pivotal role in evaluating the status and efficacy of the green economy, as it encompasses a tripartite approach encompassing environmental, social, and economic aspects. The selected variables encompass pivotal domains that, collectively, facilitate a comprehensive representation of the green economy at the provincial level. The analysis enables the identification of provinces that are effectively implementing the green economy and those that require improvement. This provides a basis for informed political and economic decisions to promote the green transition.

The features satisfying the inequality were removed from the set of variables, where V^* stands for the coefficient of variation's critical value. The critical value was determined to be $V^* = 0.10$ (Kukuła, 2000). It is considered that if the correlation coefficient between the examined features is found to be excessively high, a representative should be chosen, typically based on merits (the correlation coefficient's threshold level is typically $r^* = 0.75$) (Malina, 2004; Młodak, 2006). Using Statistica software, an exploratory factor analysis was performed, which strengthened the process of variable selection.

The definition of an observation matrix, including objects and features, was facilitated by the choice of straightforward variables and their content and statistical verification. It was written as X_{ij}:

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix} \quad (1)$$

where: X_{ij} denotes the values of the j^{th} variable ($j = 1, 2, ..., m$) for the i^{th} object ($i = 1, 2, ..., n$), matrix of objects.

Tab. 2: Descriptive statistics of variables that characterize the green economy

Variables	Average	Minimum	Maximum	Variance	Standard deviation	Coefficient of variation
Expenditure on healthcare	41.673	8.160	131.280	496.723	21.322	52.373
Spending on waste management	0.021	0.000	0.100	0.000	0.016	71.280
Expenditure on fixed assets for environmental protection and water management	376.656	206.460	753.170	8,809.878	91.668	24.188
Electricity usage in rural areas	813.533	532.200	1,055.200	13,187.505	114.735	14.109
Overall electricity generation	0.004	0.000	0.014	0.000	0.004	87.651
Electricity production from renewable sources	0.001	0.000	0.003	0.000	0.001	81.912
Proportion of agricultural land in total area	58.675	20.100	71.300	104.248	10.010	17.126
Proportion of forests in the total area	30.800	21.300	50.900	55.126	7.425	24.107
Proportion of legally protected areas in the total area	33.490	18.170	65.000	170.264	13.049	38.963
Proportion of ecological species in the total area	0.001	0.000	0.003	0.000	0.001	73.207
Proportion of active landfills in the total area	0.000	0.000	0.000	0.000	0.000	45.408
Proportion of selectively collected waste in total waste	25.392	4.300	47.900	16.259	3.795	17.044

Source: own (based on the Statistics Poland (stat.gov.pl))

The direction of the variable preferences in respect to the general criterion under consideration was ascertained in the following study stage, where they were classified as stimulants and destimulants (Wysocki, 2010). According to the classification in the set of diagnostic variables selected for the construction of the synthetic measure of green economy of voivodships in Poland, the following were distinguished: S (stimulant) = $\{X_1, X_2, \ldots, X_m\}$ = $\{X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{12}\}$ and D (destimulant) = = $\{X_1, X_2, \ldots, X_m\}$ = $\{X_{11}\}$.

It is challenging to directly compare and add diagnostic factors since they typically have distinct titers and ranges of variation (Malina, 2004). The zeroed unitarization process was applied to the chosen variables using the following formula:

$$Z_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \text{ where } x_i \in S \quad (2)$$

$$Z_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \text{ where } x_i \in D \quad (3)$$

where: S – the stimulant; D – the destimulant; i = 1, 2, …, n; j = 1, 2, ..., m; max x_{ij} – the maximum value of the j^{th} factor; min x_{ij} – the minimum value of the j^{th} factor; x_{ij} – the value of the j^{th} factor for this object (Kukuła, 2000).

Regarding their range of variability and placement inside the observation space, every variable is standardized. After unitarization, we are left with a matrix of feature values – Z_{ij} ($\in$ [0; 1]):

$$Z_{ij} = \begin{bmatrix} z_{11} & z_{12} & \ldots & z_{1m} \\ z_{21} & z_{22} & \ldots & z_{2m} \\ \ldots & \ldots & \ldots & \ldots \\ z_{n1} & z_{n2} & \ldots & z_{nm} \end{bmatrix} \quad (4)$$

The aggregation functions are used to estimate the values of the synthetic variable; these functions can take several analytical forms. Based on the following formula, the synthetic measure for each individual object was established:

$$q_i = \frac{d_i^-}{d_i^- + d_i^+} \quad (5)$$

With the proviso that: q_i [0; 1] (i = 1, 2, …, n) is the value of the synthetic measure; d_i^- represents the distance of the object from the anti-pattern (from 0), and d_i^+ represents the distance of the object from the pattern (from 1). A greater measure value denotes an improved individual's circumstances inside the examined region (Dziekański et al., 2022).

During the last phase of the study, the synthetic measure, the "green economy," was interpreted using a typological grouping. Bagged graphs were invited, the Spearman rank correlation coefficient was evaluated, and a spatial autocorrelation analysis was carried out. From the perspective of advantages of the approach, spatial autocorrelation reveals the extent to which the green economy metrics in one region are related to those in neighboring regions (to understand regional dependencies). This can help policymakers target regions with similar challenges and opportunities, enabling more region-specific interventions. By identifying areas with similar values, spatial autocorrelation helps in grouping regions with common characteristics, making it easier to tailor regional policies to specific needs. However, there are also some disadvantages, because the accuracy of spatial autocorrelation can be highly dependent on the granularity and quality of data (data limitation). In regions where data is sparse or outdated, spatial autocorrelation may not accurately reflect real patterns. The positive autocorrelation might indicate clusters of regions with both high and low green economy performance, which can complicate interpretations about which clusters should receive priority attention. Maps illustrating the spatial variation of the synthetic measure of the "green economy" were included in the outcome assessment.

Four classes were determined using the mean ($\bar{x}$) standard deviation (S_d). The first group has the most developed voivodeships, and the last group (because of the green economy measure) has the least developed voivodeships. The following formulas were used to group the data:

$$\begin{aligned} &\text{Group 1; } \bar{x} + S_d \leq q_i \\ &\text{Group 2; } \bar{x} \leq q_i < \bar{x} + S_d \\ &\text{Group 3; } \bar{x} - S_d \leq q_i < \bar{x} \\ &\text{Group 4; } q_i < \bar{x} - S_d \end{aligned} \quad (6)$$

When spatial autocorrelation is present, objects that are geographically close to each other tend to exhibit greater similarity in the variable being studied and have a tendency to form clusters. As a result, these objects can combine to form spatial clusters. When we see a spatial accumulation of high or low values for the measured variables, we get positive spatial autocorrelation. A checkerboard pattern is the visual representation of negative autocorrelation, which is defined as adjacent high values with low values and low values with high values in the space (Suchecki, 2010). Finding groups of related objects can be accomplished by examining the autocorrelation result. It is easier to anticipate changes and to implement development policy when one is aware of and comprehends the structures of space (Sikora, 2009).

A technique that allowed for the determination of whether surrounding units form clusters with similar values of the synthetic measure is the Moran's I global statistic. The following formula (Anselin, 1995; Cliff & Ord, 1973; Longley et al., 2006; Upton & Fingleton, 1985) was used to determine it:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\,(x_i-\overline{x})(x_j-\overline{x})}{S_0\,\sigma^2} \tag{7}$$

When an area is surrounded by regions that have significantly differing values for the variable under study, the local Moran's I statistic goes negative (and vice versa). As a result, clusters with either low or high values of the variable under investigation (Global Moran's statistics) can be identified. The most widely used analysis is the local variant of Moran's I statistics, or LISA (Local Indicators of Spatial Association) (Moran, 1950; Ullah & Giles, 1998). The following formula determines the local version of the Moran's I coefficient:

$$I_i = \frac{(x_i-\overline{x})\sum_{j=1}^{n} w_{ij}\,(x_j-\overline{x})}{\sigma^2} \tag{8}$$

where: n – total count of spatial objects (number of points or polygons); x_i, x_j – the values of the factors for the compared objects; $\overline{x}$ – mean value of the factors for all objects; w_{ij} – elements of the spatial weight matrix (row-standardized weight matrix);

$S_0 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}$; $\sigma^2 = \frac{\sum_{j=1}^{n}(x_i-\overline{x})^2}{n}$

– the square of the dispersion (Cliff & Ord, 1973; Longley et al., 2006).

A value from the interval (−1, 1) is used for Moran's I statistics, which show statistically significant clusters of similar values in nearby places. A value of "0" indicates no spatial autocorrelation (Janc, 2006).

Using the Queen matrix standardized by rows to one, Moran's I statistics were computed to show the regional dependency of the green economy in Poland's voivodships. The PQStat application was used to perform the computations.

3 Results and discussion

3.1 Results

The polarization in the green economy is a defining feature of Poland. Historical and ecological factors have contributed to this divergence. Larger and medium-sized cities also have an impact on it, and there is evidence of social and economic connection. It may prove challenging for voivodships (e.g., Śląskie, Dolnoślaskie) where industry plays a pivotal role in their economies to transition to more environmentally sustainable economic models. Furthermore, ecological factors, such as disparities in the accessibility of natural resources, including agricultural land, forests, and protected areas, influence the implementation of environmentally friendly measures. In 2010 and 2020, the synthetic green economy measure ranged from 0.31 to 0.42 and 0.40 to 0.53, respectively. The synthetic measure's mean, minimum, and maximum are all rising. A greater polarity of the gap is indicated by an increase in its magnitude. A decrease in polarization was shown by the synthetic measure's coefficient of variation, which had a value between 0.08 and 0.07. The reduction in the coefficient of variation may also indicate stabilisation processes in which the differences between the provinces, although they still exist, are not growing as fast as before.

The split of Poland's voivodships based on the value of the synthetic green economy metric is depicted in Fig. 2. Units with a lower measure value are shown by lighter colors, and a set of voivodeships with a larger measure value are indicated by black colors.

Tab. 3 displays a modest negative autocorrelation for the green economy measure throughout the examined time, using the calculated global values of Moran's I. A decreasing spatial reliance is indicated by the studied statistics' declining value. This implies that

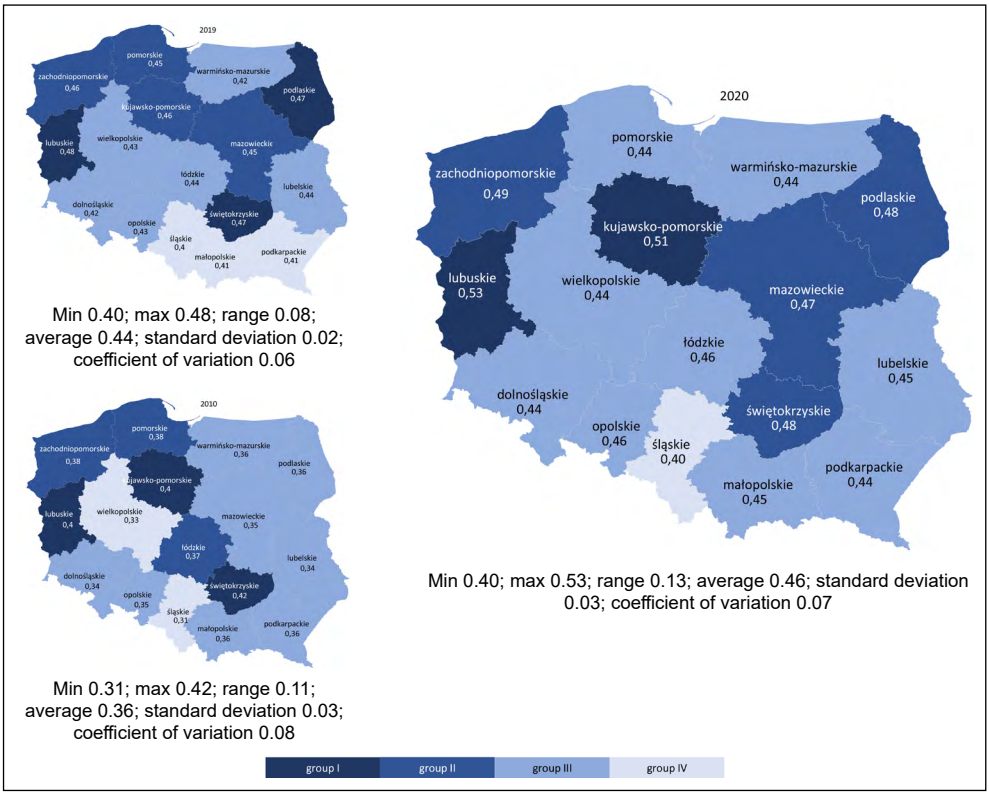

Fig. 2: **Synthetic measure of green economy in voivodships in Poland (2010, 2019, 2020)**

Source: own (based on the Statistic Poland data)

Tab. 3: **Synthetic green economy measure in Poland's voivodships by Moran's I (2010, 2019, 2020)**

	2010	2019	2020
Moran's I	−0.195	−0.026	−0.130
Expected I	−0.067	−0.067	−0.067
Assuming normality			
Variance I	0.022	0.022	0.022
Statistics *Z*	−0.864	0.276	−0.427
Value *p*	0.388	0.783	0.670
Assuming randomness			
Variance I	0.022	0.024	0.021
Statistics *Z*	−0.866	0.267	−0.436
Value *p*	0.386	0.789	0.663

Source: own (based on Statistics Poland data)

every level of the green economy that has been observed has an equal chance of occurring somewhere. In terms of voivodships, it may be said that the green economy does not exhibit spatial autocorrelation. This indicates a propensity to concentrate comparable values, or high and low values, on the researched variable's area inside a certain location.

In the subsequent analytical stage, local Moran's I statistics were calculated for each voivodeship (with their spatial differentiation illustrated in Fig. 3). The following voivodeships exhibited significant and positive values of the local Moran's I statistics: Opolskie (0.422), Zachodniopomorskie (0.146), Pomorskie (0.093), Dolnośląskie (0.091), Podlaskie (0.052) in 2010 (Zachodniopomorskie 0.252, Małopolskie 0.239, Mazowieckie 0.077, Oposkie 0.033, Podkarpackie 0.027; in 2020), which suggests the presence of local clusters with similar levels of green economy. This implies that these provinces were more consistent in terms of green policies, with a tendency to spatially concentrate similar results. The negative was obtained for the following voivodeships: Lubelskie (−0.272), Wielkopolskie (−0.464), Lubuskie (−0.608), Śląskie (−0.792), Świętokrzyskie (−1.057) in 2010

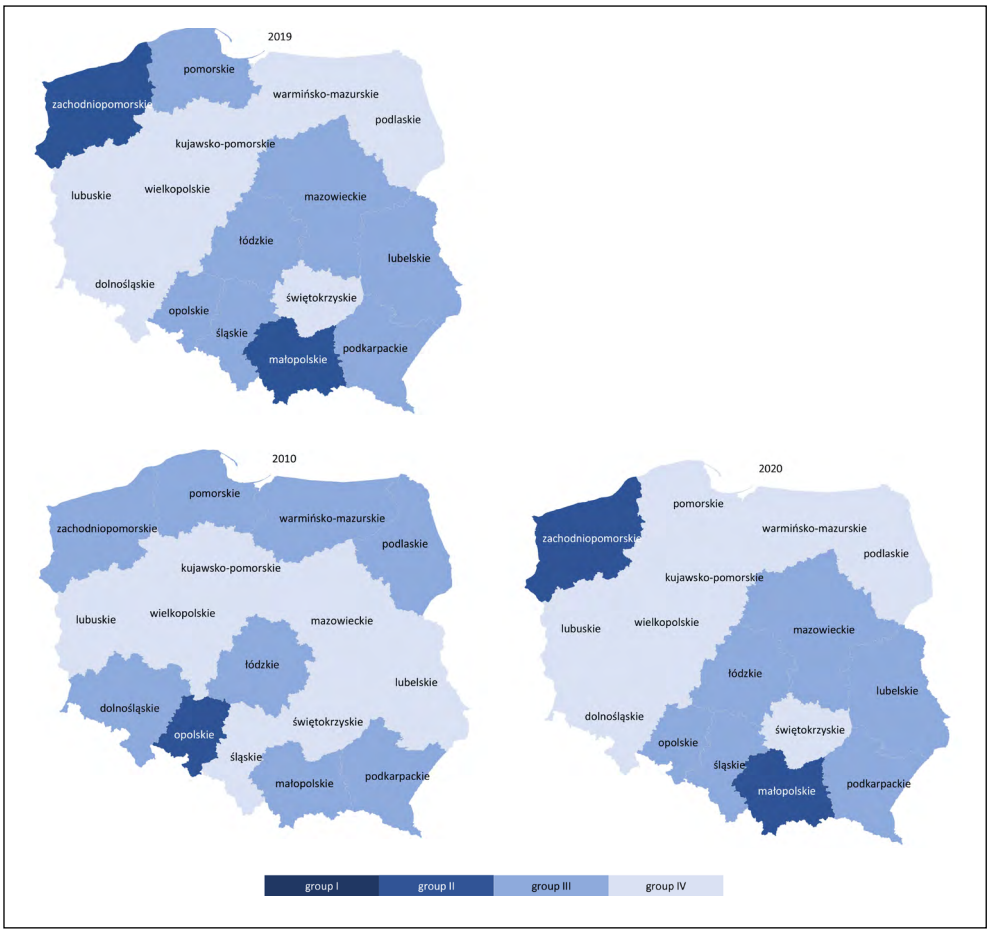

Fig. 3: **Synthetic green economy measure in Poland's voivodships by local Moran's I (2010, 2019, 2020)**

Source: own (based on Statistic Poland data)

(Świętokrzyskie −0.305, Wielkopolskie −0.308, Lubuskie −0.316, Dolnośląskie −0.328, Kujawskopomorskie −0.549; in 2020), indicating a spatial split and lack of strong links between high and low green economy regions. This situation may suggest that there is a divergence in the implementation of environmental policies in these provinces or other factors that prevent their effective implementation across the region. This phenomenon may be due to various conditions, such as the structure of the economy, the availability of financial resources for environmental investment, or the diversity of green infrastructure.

The western, eastern, and central provinces of Poland (Zachodniopomorskie, Małopolskie and Mazowieckie) exhibited elevated values for the Moran statistic, which may suggest an enhancement in the consistency with which green economy measures are implemented. This may indicate an improvement in the effectiveness of green policies and their more effective implementation, which has resulted in a greater concentration of results in these provinces. It may be posited that these changes are the consequence of an increased focus on green transformation within national and regional development strategies, coupled with a rise in environmental awareness and the mobilisation of resources to achieve sustainable development goals. Conversely, voivodeships such as Świętokrzyskie, Wielkopolskie, Lubuskie and Kujawsko-Pomorskie exhibited negative values, indicating that these regions remain less integrated with regard to green policies and green development. This may indicate that there is still a divergence of green economy measures within them, and that there is a significant spatial variation in the level of implementation of these measures. This points to the possibility of difficulties in implementing unified green policies in these provinces, which may be due to a variety of local challenges, such as lower levels of investment in green infrastructure, greater reliance on traditional industries or difficulties in integrating actions at the local level.

Fig. 4 shows the relationships between variables in pairs and pinpoints data clusters. Groups of statistically comparable voivodeships, including outliers, are shown in the bag chart. The visual shape of these groups in succeeding years may suggest their distinction. The changes in the shape of the groups indicate the dynamics processes involved in the implementation of the green economy, as well as differences in the development of the provinces. Pearson correlation coefficient between q quality of life and q green economy and the value of the synthetic green economy measure: −0.1424, −0.2324, and −0.1654 (2010, 2019, and 2020) and with q financial situation: −0.2639, −0.1703, and 0.1680. This suggests that the spatial differentiation within the study area was relatively unstable (this is also indicated by the shape of the bags in the Fig. 4). In 2020, the outliers in our relations were two voivodeships: Silesian, Masovian, Lubusz, and Lublin Voivodship (Śląskie, Mazowieckie, Lubuskie, Lubelskie). These values suggest that improvements in the quality of life do not always go hand in hand with the development of green activities, and that external factors such as the financial situation or the level of infrastructure development may have a greater influence on these variables. The results of the analysis indicate that the spatial differentiation of the green economy in Poland is unstable and variable, suggesting that changes in this area do not occur uniformly. This variation may be the result of both local socio-economic conditions and specific regional policies, which have different impacts on the implementation of green activities. Variations in the correlations between variables also indicate the difficulty of achieving consistent, positive effects of the green economy across the country.

The relative change 2020/2019 and the measure's level in 2020 had a Pearson correlation value of 0.5795. This means that over this period, there has been a significant increase in the relationship between the level of the green economy and the changing dynamics of its development in different provinces. This is where the change 2020/2010 had a coefficient of 0.1953. Such a result suggests that, despite some progress in the development of the green economy, changes in the green economy were less dynamic and the relationship between 2010 and 2020 was less clear. The scatterplot displays a change in spatial polarization. In the two relationships under investigation, the top regions were: Pomorskie, Kujawsko-Pomorskie, Śląskie, Lubuskie (Fig. 5). This may indicate the effectiveness of the environmental policies implemented in these provinces, as well as their greater willingness to invest in sectors related to environmental protection and sustainable development.

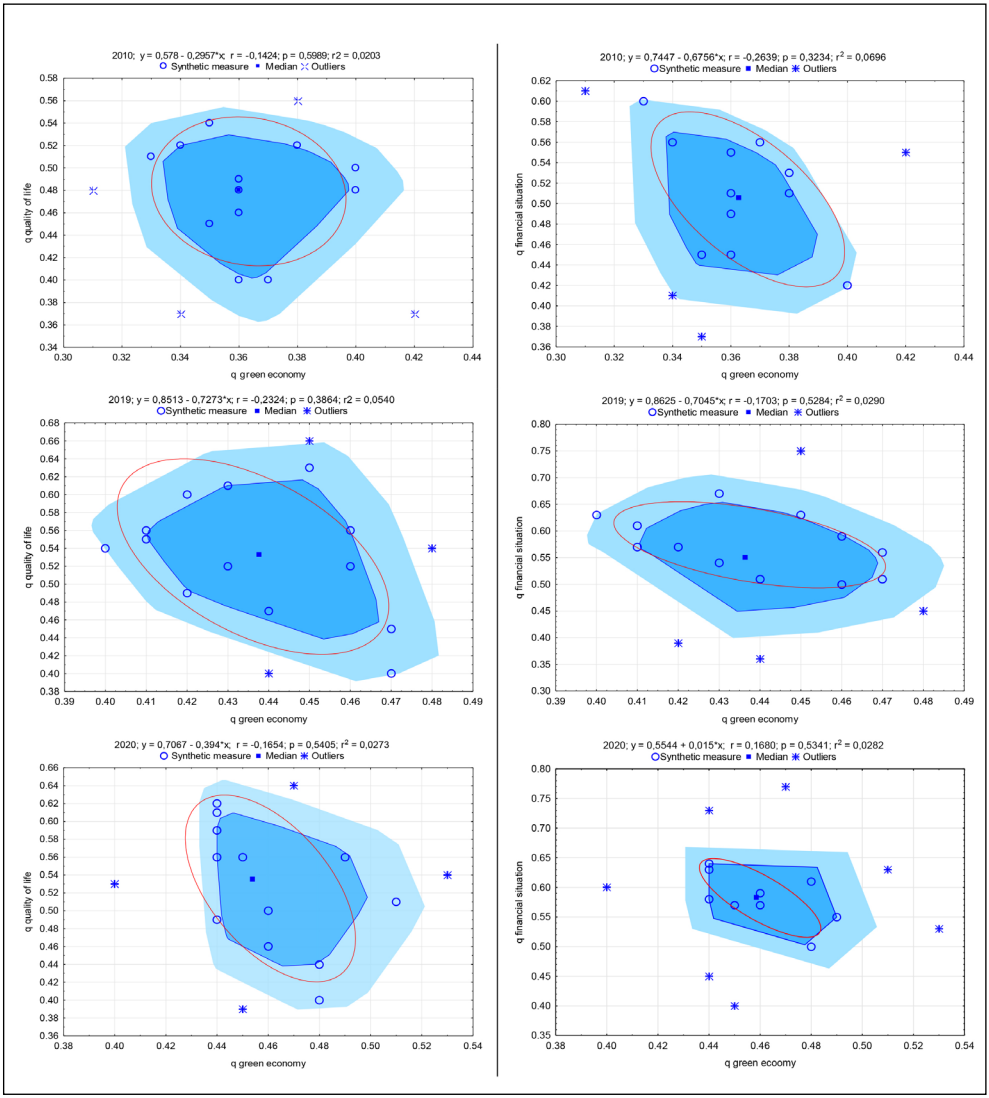

Fig. 4: **Relation of green economy measure with quality of life and financial situation in Poland's voivodships (2010, 2019, 2020)**

Source: own (based on the Statistic Poland data)

The findings of Spearman's rank correlation between the socio-economic factors that influence the green economy and its synthetic measure are displayed in Tab. 4. Spending on fixed assets for water management and environmental protection in 2010 had a positive impact on the indicator (0.502), the proportion of legally protected areas within the entire area (0.426), electricity production from renewable sources (0.349), and negatively shaped by the financial situation (−0.234), the share of active landfills in the total area (−0.238), electricity consumption (rural areas; −0.273), and the share of selectively collected waste in total waste (−0.306). Provinces that struggled with more waste and higher levels of energy consumption were less

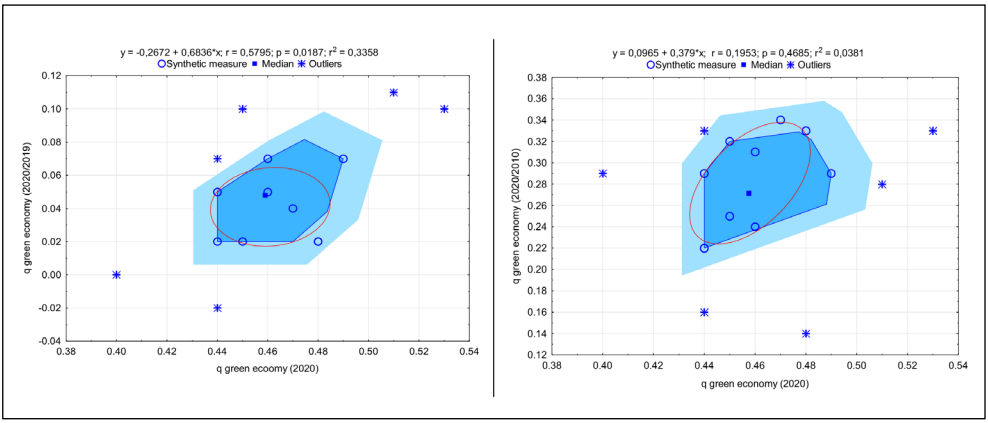

Fig. 5: **Relationship between green economy measure and relative changes (2020/2019, 2020/2010) in Poland's Voivodeships**

Source: own study based on the Statistic Poland data

Tab. 4: **Results of the synthetic measure of green economy's Spearman's range correlation with socio-economic indicators in Polish provinces (2010, 2019, 2020)**

Variables	2010	2019	2020
***q* quality of life**	−0.063	−0.240	−0.269
***q* financial situation**	−0.234	−0.290	−0.192
Expenditure on health care	0.248	0.395	0.399
Spending on waste management	−0.012	−0.213	−0.092
Expenditure on fixed assets for environmental protection and water management	0.502	−0.466	−0.293
Electricity usage in rural areasconsumption (rural areas)	−0.273	−0.035	0.048
Overall electricity generation	−0.070	0.167	0.344
Electricity production from renewable sources	0.349	0.691	0.537
Proportion of agricultural land in total area	−0.189	0.040	0.201
Proportion of forests in the total area	0.227	−0.018	−0.129
Proportion of legally protected areas in the total area	0.426	0.112	0.127
Proportion of ecological species in the total area	0.244	0.384	0.302
Proportion of active landfills in the total area	−0.238	−0.206	0.032
Proportion of selectively collected waste in total waste	−0.306	−0.305	−0.344

Note: Correlation coefficients are significant with $p < 0.05$.

Source: own (based on Statistic Poland data)

effective in implementing the green economy. In 2020, renewable electricity generation (0.537), healthcare expenditure (0.399), total electricity generation (0.344), and the financial situation (−0.192), quality of life (−0.269), expenditure on environmental and water management fixed assets (−0.293), and the share of selectively collected waste in total waste (−0.344) were respectively ranked. This indicates challenges in waste management, which may have a diminishing effect on the effectiveness of the green economy. Spearman's rank correlation results for 2010 and 2020 show that some social and economic variables have a lasting impact on the development of the green economy in Poland, but the correlations vary with the time context. The correlation values indicate the need for further development of policies that integrate environmental issues with infrastructure development and improvement of the quality of life and financial situation of the provinces.

In order to accelerate Poland's transformation towards a green economy, it is recommended to strengthen regional policies that integrate environmental protection with the development of green infrastructure and the improvement of quality of life. Particular attention should be paid to regions with lower values of the synthetic green economy measure, such as Świętokrzyskie, Wielkopolskie, or Lubuskie, by increasing investments in green infrastructure, renewable energy sources, and effective waste management. In addition, it is necessary to combine spending on environmental protection with improvements in the financial situation and quality of life of residents in order to promote dynamic development. Regions with higher synthetic measures, such as Pomorskie or Kujawsko-Pomorskie, can play a leading role by sharing their experiences and best practices, which will help to reduce polarization between provinces and improve the efficiency of actions at the national level.

3.2 Discussion

In Poland, polarization is evident with regard to the green economy. The local Moran I statistics shows growing disparities between provinces in the implementation of green economy policies. An increase in the value of the synthetic measure of the green economy and a decrease in the coefficient of variation indicate progress but also the need for further action to reduce disparities in this area. Positive values (Zachodniopomorskie, Małopolskie, Mazowieckie, Opolskie, Podkarpackie) indicate a greater concentration and consistency of pro-environmental activities in some voivodeships, which may indicate better environmental management. On the other hand, negative values (Świętokrzyskie, Wielkopolskie, Lubuskie, Dolnośląskie, Kujawsko-Pomorskie) indicate challenges related to the integration of environmental actions in other regions, which may require more coordinated action at the local and regional level.

Dependence on coal has shaped the economies of many regions for many years, and this has had a significant impact on the pace of adaptation to the green economy, mainly due to structural, social, and economic conditions. These transitions require time, investment, and public policy support to be implemented in a sustainable and equitable manner. Provinces with higher spending on health care may also have higher spending on waste management as part of a comprehensive sustainable development policy in which citizens' health and waste management are interlinked. Provinces with higher spending on health care may also have higher spending on waste management as part of a comprehensive sustainable development policy in which citizens' health and waste management are interlinked.

The indicators used in the study take into account a number of variables of key importance for the green economy at the provincial level, including expenditure on health care, waste management, and investment in fixed assets for environmental protection and water management; electricity consumption in rural areas; electricity production from renewable sources; agricultural land; forests; or legally protected areas. These indicators allow an overall assessment of the development of the green economy in different regions of Poland and make it possible to compare the results in terms of the effectiveness of pro-environmental policies.

The evaluation of the polarization and clustering of the green economy in the Polish voivodeships was made feasible by the synthetic measure of the green economy and the Moran autocorrelation measures computed on this basis. The evaluation was predicated on factors pertaining to waste levels, natural capital, state policy, socio-economic issues, and environmental conditions (Tab. 1). The availability

of empirical data gathered at a particular administrative level affects how the green economy is measured. This article's methodical methodology can broaden our understanding of GE shifts at the regional level. Since it has so many definitions and facets, it is challenging to define the notion of GE. The challenge, as stated by Lukas (2015), is figuring out what components contribute to GE. Developing nations incur significant costs during the switch to GE.

The authors' methodology for their analysis involved selecting a variety of metrics that, in their opinion, accurately represented the green economy (Tab. 1). This strategy is used and quite frequent (OECD, UNEP). The main goal of this strategy is to identify metrics that accurately capture the interplay between the environment and the economy or society in the studied region. It appears that the question of regional GE difference is the most significant topic in the field of study being conducted. This issue is related to the analysis of the consistency or lack thereof of the application of sustainable development.

In the context of Poland, a key issue remains the analysis of regional differences in the implementation of green economy objectives. These differences, which are the result of local conditions, are of great importance for assessing the coherence, or rather the lack of it, in the implementation of sustainable development policy in the country. In particular, the heterogeneity of the results of the analysis of the synthetic measure of the green economy between provinces indicates the need for further research into the factors that shape these differences, such as the specifics of the regional economy, natural resources, the level of urbanization, or the effectiveness of the implementation of public policies. Thus, the issue of regional differences in the green economy not only highlights the importance of local conditions but also challenges politicians and policymakers to take these differences into account when designing green policies. However, as Wyszkowska and Artemiuk (2016) point out, this requires taking actions that include the sustainable use of natural capital, maintaining the capacity of ecosystems to provide certain services, and ensuring good environmental quality without negative impacts on the health and livelihoods of citizens. These actions should make it possible to reconcile economic growth with environmental concerns.

Li et al. (2022) state that GE acknowledges shifts in consumer awareness and investments in renewable energy as ways it supports sustainable development and environmental protection. GE needs to acknowledge the limitations imposed by the environment and the economy, including the degree and composition of the endogenous territorial division. By doing so, the steps taken should be optimized, and resource conservation should take precedence over environmental deterioration. D'Amato and Korhonen (2021) have demonstrated that natural resources are a crucial component of economic and social progress. However, inadequate resource usage has resulted in resource depletion and environmental degradation, endangering both human welfare and the ecosystem. Additionally, GE helps authorities at the local, regional, national, and international levels identify sustainability concerns and operationalize solutions.

Houssam et al. (2023) claim that in addition to the effects of climate change and the fuel, food, and financial crises, the depletion of natural resources, the destruction of ecosystems, and the loss of biodiversity are driving national and regional authorities to find practical solutions for the problems of ecological constraint and biodiversity. Various entities are forced to take action to improve the efficiency of environmental resources' usage in the manufacturing process due to the systematic growth in their consumption, particularly non-renewable resources. As Wyszkowska (2016) notes, it is beneficial to have a permanent green economic ocean. It ought to offer data on which actors can base their decisions.

According to Dace et al. (2024), a circular bioeconomy must replace a linear fossil fuel-based economy. There are several obstacles standing in the way of the shift to a sustainable closed-loop bioeconomy, including technological, social, political, and structural ones. The externalities to the environment might impede green growth if producers and/or consumers are encouraged to pollute more, as noted by Sarkodie et al. (2024). In the face of global environmental changes, and in the context of ensuring food security, there is a growing need for the economy to switch to renewable energy sources and move towards sustainable production and consumption patterns. Shifting to a more sustainable economy through more efficient use and effective management of biological resources

can contribute to reducing waste, pollution, and climate change while reducing pressure on fossil resources (Luczka, 2018).

However, the environmental context and the need to develop technological innovations that will enable the transformation of the EU economy towards a low-carbon and climate-neutral economy should not be forgotten. From the perspective of the European Union, it is crucial to achieve climate neutrality and to fully implement a model of sustainable development in which social and environmental issues are important alongside economic performance. As a result, the development of technological innovation in the energy sector is becoming increasingly important (Tomala & Urbaniec, 2024). The effectiveness of the green economy is often revealed through the characteristics of regional heterogeneity in space, meaning that different regions may have different levels of sophistication and effectiveness of green policies. However, regardless of the specificities of regions, the green economy, as a holistic strategy to address environmental, social, and economic issues, plays a key role in sustainable development. From a development perspective, reducing the use of natural resources becomes a necessary step that will contribute to improving environmental conditions. Such changes not only support environmental protection but also promote innovative approaches to resource management that can lead to more sustainable and resilient economic development in the long term. Implementing the green economy in different regions therefore requires appropriate policies and investments that take into account local needs and potential and motivate action to protect the environment and care for future generations.

Conclusions

The results of the research, which is based on the spatial autocorrelation of the green economy and takes into account variables such as expenditure on health care, waste management, investment in environmental protection, electricity production (including from renewable sources), and management of natural resources (e.g., agricultural land, forests, protected areas), are important because they provide a comprehensive picture of the state of the green economy in individual Polish provinces. This makes it possible to identify areas that are making progress in implementing green policies and those that still face challenges in this regard. There is a significant positive spatial autocorrelation of green economy indicators in individual regions of Poland, indicating that regions with high green economy performance tend to cluster together. Voivodships with a historically high dependence on coal show lower green economy growth rates than others. Expenditure on health care and waste management are positively autocorrelated, indicating the mutual influence of these two areas on green economy growth.

Local Moran I statistics show increasing disparities between provinces in the implementation of green economy policies. Although we see progress in the synthetic measure of the green economy and a reduction in variability, action is still needed to reduce disparities. Positive values (e.g., in Zachodniopomorskie, Małopolskie, Mazowieckie) indicate greater consistency in green policies, while negative values (e.g., in Świętokrzyskie, Wielkopolskie, Lubuskie) indicate challenges in integrating green policies in these regions.

The green economy's efficacy frequently demonstrates characteristics of regional heterogeneity in space. A holistic strategy for addressing environmental, social, and economic issues is the "green economy." It calls for the prudent use of resources, a decrease in waste and pollution, the protection of biodiversity, the encouragement of innovation, and the effective use of available resources.

Energy and resource efficiency should increase throughout regions. The green economy can serve as a foundation for policy development, investment (especially in clean technology), waste management, renewable energy, transportation, and renewable energy. Green economy initiatives by regional governments ought to encourage advancements in sustainability as well as increased efficiency. Reducing the usage of natural resources is imperative at this point in development, as it will contribute to better environmental conditions.

With the help of autocorrelation analysis and a synthetic measure, the given model enables comparisons between units and the display of changes in the studied phenomenon over time in the studied area. By using the spatial autocorrelation method, one may determine which parts of voivodships have comparable values of the phenomenon under study and

can also observe the impact of geographical interdependence between neighboring voivodships. One benefit of spatial autocorrelation is that it may be used to describe the spatial differentiation of the area under analysis. This can be done by using maps and specific values of local and global statistics. It is a helpful tool in the study of regional development since it enables a deeper understanding of the dependencies that already exist. In this context, spatial autocorrelation helps to isolate key areas that may show common characteristics or development trends, which is of great importance in the analysis of regional differences and cohesion.

Systematic studies on the green economy should give regional authorities the knowledge they need to evaluate and adjust the actions taken in connection with the examined field (such as the green economy, green development), taking into account any discrepancies that may exist between units. The findings will also provide direction for potential steps to lessen polarization within the GE amongst voivodships and enable comparisons between voivodships (while preserving the same technique and variables). The study methodology can be expanded to take into account new areas that may affect the level of GE, such as demography, ecology, infrastructure, and entrepreneurship. It may also involve examining the direction and strength of outlier variables' influence on the primary criterion, as well as exploring new methods for evaluating autocorrelation. New diagnostic variables can be added, and analyses can be conducted over longer time periods.

The research is limited by the data's accessibility within official statistical frameworks, its comparability, evolving laws, shifting socioeconomic conditions, and chance occurrences. Specifically, the selection of years (2010, 2019, and 2020) for the analysis, while guided by significant economic events, such as post-crisis recovery and the COVID-19 pandemic, limits the ability to observe trends over a continuous timeline. Including data from intermediate years might have provided a more nuanced understanding of the progression and challenges of the green economy over time. Also, the reliance on certain regional-level data may not fully capture the complexities of local-level economic and environmental interactions. This limitation might result in an oversimplification of how specific factors, such as waste management expenditure or renewable energy generation, directly affect green economy performance at more localized levels.

Future research should aim to address these limitations by incorporating more continuous time-series data to offer a clearer view of green economy trends over time. Additionally, further research could focus on cross-country comparisons or smaller geographical scales to provide more localized insights into the factors driving green economy growth. Research on a larger sample of diagnostic variables to better understand the determinants of green economy development and longer timeframes will enable capturing dynamic changes, forecasting trends and better planning of regional development strategies. It would also be valuable to explore the long-term effects of significant disruptions, such as the COVID-19 pandemic, on the green economy in more detail.

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Carbon emission trading policy and green technological innovation in Chinese listed companies: A corporate reputation perspective

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Abstract: *The carbon emission trading policy (CET) makes enterprises' pollution information transparent and is an important environmental regulation tool for China to achieve the goal of "carbon peak" and "carbon neutrality." Taking A-share listed companies in China's Shanghai and Shenzhen stock exchange from 2008 to 2021 as a research sample, this paper chooses the implementation of China's carbon emission trading policy in seven pilot regions as a quasi-natural experimental scenario and takes 2014 as the inception time of the policy to construct the difference-in-difference model with the fixed effect. The research then employs a multiple regression model and other statistical methods, such as an event study and placebo test, to examine the impact and mechanism of carbon emission trading policies on companies' green technological innovation. The study reveals that CET significantly improves enterprises' green technological innovation, attributed to weighing benefits against costs and preserving corporate reputation. Compared to purchasing carbon quotas for a long time, green technological innovation is a sustainable development strategy for enterprises, saving pollution costs and enhancing corporate reputation. The effect of CET on green technological innovation is more pronounced in larger enterprises, polluting industries, and regions where policy implementation is more rigorous. Enterprises that carry out green technological innovation to comply with CET can enjoy better reputations and lower financial costs. This study enriches and expands the research horizon of the impact of carbon trading policy on enterprises' green technological innovation, examining it from both theoretical and empirical perspectives. It demonstrates that green technological innovation is a long-term strategic choice for enterprises, providing implications for achieving superior policy advantages. In addition, the research shows that CET alleviates information asymmetry and facilitates the disclosure of carbon information, offering an opportunity for external stakeholders to better oversee their corporations.*

Keywords: *Carbon emission trading policy, corporate green technological innovation, corporate reputation perspective, equilibrium of costs and benefits, alleviate information asymmetry.*

JEL Classification: *D22, L20, L51, O30, Q58, Q59.*

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Introduction

Carbon emissions are one of the leading causes of global warming, and excessive carbon emissions contribute to frequent extreme weather events and harm human health. In response to this global challenge, a series of international conventions, including the Kyoto Protocol and the Paris Agreement, have been introduced to reduce carbon emissions through global cooperation. The carbon emission trading policy (CET) is one of the most important market-based regulations, which follows the principle of "cap and trade" and allows enterprises to trade carbon emission quotas within the specified total limit. As the world's earliest and largest carbon emission trading market, the EU Emissions trading system (EU-ETS) has effectively reduced carbon emissions and fostered the development of low-carbon technology. In this international context, President Xi announced that China strives to achieve its goal of peaking carbon dioxide emissions by 2030 and achieving carbon neutrality by 2060. To protect the environment and achieve carbon peaking and neutrality goals, the Chinese government issued a Notice on carrying out the pilot work of carbon emissions trading, which approved seven regions to lead the start of carbon emissions trading (CET). Subsequently, the scope of the carbon trading market in China has gradually expanded, and the corresponding institutional oversight has improved considerably.

With this backdrop, enterprises, as one of the main participants in CET, actively adjust their strategies to adapt to the development of the carbon market. Green technological innovation is a crucial strategy for balancing environmental protection and economic growth, and it is also a widely recognized means of achieving sustainable development (Huang & Li, 2017). However, the results of existing research on the role of CET in influencing corporate green innovation are inconclusive. Some scholars support the Porter effect, believing that effective environmental regulation can promote enterprises' green technological innovation (Porter & Linde, 1995), while others argue that environmental policies will crowd out enterprises' resources and hinder innovation (Wang et al., 2022). In addition, existing research mechanisms on the impact of CET on enterprises' green technological innovation primarily focus on the government and market perspectives, taking into account factors such as policy intensity, carbon quota allocation method, carbon price, and market competition intensity (Tian et al., 2022). However, there is a lack of consideration for the internal motivations of enterprises to conduct green technological innovation and the impact of informal supervision by external stakeholders under the CET.

In fact, as the carbon market matures, the price of carbon quotas is expected to increase due to shifts in supply and demand. Green technological innovation can help companies reduce emissions and meet their carbon quota demands. Meanwhile, the CET allows enterprises to profit from the sale of surplus carbon quotas. Thus, the benefits of green technological innovation are internalized. Besides that, the CET makes the carbon emission information of enterprises transparent; it will directly damage the firm's reputation and performance when their poor environmental actions are revealed. To summarize, our paper proposes the hypothesis that CET can foster companies' green technological innovation. To test this hypothesis, our study selects data from 2008 to 2021 for China's Shanghai and Shenzhen A-share listed companies, which are ordinary shares issued by Chinese companies and denominated in RMB, as a research sample. By utilizing the implementation of China's CET in seven pilot regions as a quasi-natural experimental scenario, the study employs the difference-in-differences model with fixed effects for empirical testing.

The paper makes several contributions in the following ways. Firstly, based on the ideal quasi-natural experimental environment created by China's carbon trading pilot, the impact of CET on enterprises' green

innovation is analyzed from the perspectives of internal cost decision-making and external stakeholder supervision, thereby enriching the relevant literature on the effects of environmental incentive-based policies on enterprise decision-making. Moreover, we conduct in-depth research on the impact of CET on companies' green innovation based on diverse corporate attributes such as the firm's size, the degree of environmental pollution, and the intensity of policy implementation. Furthermore, we examine the proposed association at the corporate, industry, and regional levels to account for the heterogeneous effects. The heterogeneity test results at the corporate, industry and regional levels reveal the important groups and the necessity of rigorous policy implementation, providing a theoretical basis for improving the CET. Finally, the study findings corroborate that implementing CET has a significantly positive influence on the transformation and upgrading of corporate green innovation and sustainable economic development. The results of this research provide empirical evidence of the CET's favorable economic and environmental outcomes, thus providing theoretical support for the carbon market operations in emerging economies. Furthermore, these findings lend credence to CET's continuous improvement and robust implementation.

1 Theoretical background

As a crucial policy in environmental regulation, the CET aims to incentivize enterprises to reduce their carbon emissions actively. Its basic principle is "cap and trade," which means the government allocate carbon quotas for enterprises, and they can trade the quotas within the total carbon emissions cap (Guan et al., 2023). The EU-ETS, the world's first carbon market, was established in 2005. Over the past two decades, EU-ETS has explored the transition of allocation methods from free allocation to auction-based allocation (Wang et al. 2018). Subsequently, Australia, South Korea, and other countries have also established their carbon markets and implemented allocation methods, such as fixed-price allocation and historical price allocation, tailored to their national conditions (Kim, 2014; Rossetto, 2023).

Despite differences in development levels, allocation methods, and coverage scopes among international carbon markets, these markets all influence corporations' environmental decisions, forcing them to choose between trading carbon quotas and pursuing green technological innovation (Herman, 2024). Scholars who support the Porter effect argue that the CET creates a reasonable and stringent environment to foster corporate green innovation (Porter & Linde, 1995). Still, some scholars believe that the pollution cost brought by CET will squeeze out corporates' resources and hinder green innovation (Wang et al., 2022). CET offers enterprises the opportunity to purchase quotas, which can serve as a substitute for green innovation (Zhang & Wu, 2022). In further discussion of current studies, external pressure is the main motivation of enterprises' green innovation under the CET. Their mechanisms are mostly from the perspective of the government, market and specific managerial traits, finds that under the CET, strong policy signals, strict formal supervision, reasonable quota allocation methods, fierce market competition and managerial overconfidence will promote green innovation (Tian et al., 2022; Wen et al., 2023). However, there is a research gap for the effect of internal motivations and informal supervision to the impact of CET on corporations' green technological innovation.

Benefitting from the experience of the international carbon market and the unique strengths of the Chinese system, the obvious advantages have been demonstrated in the establishment of the CET in China. Furthermore, as a pilot policy, China's CET also provides an ideal quasi-natural experiment setting for research. Therefore, our paper takes China's CET as the research background and enriches the research topic by focusing on the enterprise's perspective on balancing costs and benefits, as well as reputation maintenance motivation, to examine the impact of CET on green innovation among listed companies in China. Unlike the perspective of external formal pressure motivation, our research examines the effects of the enterprise's internal motivation and informal external supervision. The mechanisms are thoroughly tested by examining the moderating effects of the firms' responses to carbon trading prices, enterprises' overall innovation capabilities, media attention, and analyst attention. Furthermore, our study examines the economic consequences of companies' green innovation triggered by CET. It conducts heterogeneity tests at the enterprise, industry and regional levels to offer an in-depth understanding of this relationship.

1.1 Hypothesis development

Companies are the main participants of CET. As an organization with economic rationality, a firm's decision-making relies on balancing benefits and costs. Hence, the decisions are only more viable when the expected benefits exceed the perceived costs. Under the CET, firms with insufficient carbon quotas have the opportunity to purchase additional quotas, while enterprises with excessive carbon quotas can generate profits by selling their excess quotas (Yu et al., 2022). Firms should thoroughly consider their resource endowments and technological advantages to maximize profits and make informed decisions about whether to purchase carbon quotas or develop green innovations (Qi & Duan, 2022). From a cost perspective, companies are increasingly participating in the carbon trading market, thereby increasing demand for carbon quotas. According to the operational experience of the EU-ETS, the free carbon quotas available for distribution in the market will gradually decline (Koch et al., 2016). As a result, the carbon quota price will rise, increasing the cost for enterprises that need to purchase it.

The theory of induced innovation believes that the rise in the relative price of production factors will inevitably encourage enterprises to invent new methods to replace the expensive ones (Hicks, 1932). Therefore, enterprises are inclined to undertake green innovation to avoid the high costs associated with carbon quotas. From a benefits standpoint, CET internalizes the external costs of carbon emissions and the benefits of green innovation, thereby causing an innovation compensation effect (Borghesi et al., 2015). The profits firms obtain through CET can compensate for the costs incurred for green innovation; hence, the expected return increases (Porter & Linde, 1995). The earlier enterprises adopt green innovation, the sooner they can benefit from it and capitalize on market opportunities. Thus, such firms are incentivized to undertake green innovation that is at least comparable to the average level of other companies (Chen et al., 2006). In a nutshell, through the rational balance of benefit and cost, optimizing green innovation is an inevitable option for companies under CET.

Reputation is an essential intangible asset accumulated by firms for a long time to garner social recognition and subsequently gain resources, opportunities and support (Wang & Xie, 2022). Firms with a strong corporate image tend to maintain more stable cooperative relationships with their stakeholders. On the contrary, a bad reputation will cause the company to lose public trust and market share. Therefore, enterprises must account for the perceived reputation in their corporate decision-making. For reputation maintenance, companies actively convey positive signals to the market while deliberately hiding negative information and opportunistic behaviors (Deegan & Rankin, 1996). CET provides a trading market for carbon quotas, and the marketization mechanism makes carbon information open and transparent, significantly alleviating the information asymmetry problem. Additionally, the mandatory requirement for firms to publish carbon emission reports helps prevent the issue of incomplete and inaccurate disclosure of carbon information. It reflects the actual carbon emissions of enterprises (Liu et al., 2019).

Under the CET, companies that consistently choose to purchase carbon quotas convey a signal of high pollution and low social responsibility, which ultimately damages their corporate reputation. By contrast, companies that actively pursue green technology innovation and achieve low emissions demonstrate a more environmentally friendly attitude and social responsibility, gaining a favorable market reputation and attracting more investments (Liu et al., 2021). Therefore, when CET allows external stakeholders to obtain accurate information on corporate carbon emissions, firms opt for green innovation to maintain a good reputation rather than purchasing carbon quotas. That is, under CET, enterprises have the motivation to undertake more environmentally friendly innovations to preserve their corporate image.

H1: Ceteris paribus, the carbon emission trading policy can promote companies' green technological innovation.

2 Research methodology

This study selects the data of A-share listed companies in China's Shanghai and Shenzhen stock exchange from 2008 to 2021 as research sample, and the dataset has been screened as follows: (1) the samples of particular transfer corporate and special treatment corporate are deleted; (2) due to the particularity of the financial industry, the samples of firms from this industry are deleted; (3) the abnormal samples

(asset-liability ratio is greater than 1) are deleted; and (4) the samples with missing data are deleted. Moreover, to avoid the influence of extreme values, all continuous variables are winsorized at the 0.01 and 0.99 levels. Our final sample contains 31,408 valid observations. The data is mainly extracted from CSMAR and CNRDS. Meanwhile, the variable assignment of CET is carried out manually.

To empirically examine the impact of CET on companies' green technological innovation, the difference-in-differences model is constructed as follows (Geng & Luo, 2022).

$$GI_{it} = \beta_0 + \beta_1 Tre_i + \beta_2 Pos_t + \\ + \beta_3 Tre\_Pos_t + \gamma Control_{it} + \varepsilon_{it} \quad (1)$$

where: GI_{it} – companies' green technological innovation; Tre_i – pilot regions; Pos_t – starting time; $Tre_i\_Pos_t$ – carbon emission trading policy; $Control_{it}$ – control variables; ε_{it} – random error term.

GI is measured by the number of firms' green technology patent applications. Logarithmic processing is performed after adding one to the number of companies' green technology patent applications to avoid generating zero value (Ma & Hu, 2022). *Tre_Pos* is the cross-multiplication term of *Tre* and *Pos*, where *Tre* is a grouping dummy variable. When the enterprise is located in the pilot regions of CET, it takes a value of 1; otherwise, it takes a value of 0. Additionally, considering that the inception time of CET in pilot regions is concentrated at the end of 2013 and the first half of 2014, *Pos* is assigned 2014 as the boundary; it takes 0 if the starting time is before 2014, and otherwise, it takes 1. For control variables, company size (*Size*), leverage ratio *(Lev*), growth ability (*Growth*), profitability (*ROE*), cash holding level (*Cash*), property rights (*State*), enterprise value (*TobinQ*), equity concentration (*Top*1), proportion of independent directors

Tab. 1: Variable definitions

Variable	Code	Definition
Companies' green technological innovation	*GI*	Ln (green technology patent applications + 1)
Pilot regions	*Tre*	1 if the enterprise is located in *the* pilot regions of CET, 0 otherwise
Starting time	*Pos*	0 if the starting time is before 2014, 1 otherwise
Carbon emission trading policy	*Tre_Pos*	The cross-multiplication term of *Tre* and *Pos*
Company size	*Size*	Ln (total assets)
Leverage ratio	*Lev*	Total liabilities/total assets
Growth ability	*Growth*	The growth rate of total assets
Profitability	*ROE*	Net profits/shareholder equity
Cash holding level	*Cash*	Cash/total assets
Property rights	*State*	State-owned enterprises take 1, otherwise 0
Enterprise value	*TobinQ*	Market value/(total assets-net intangible assets-goodwill)
Equity concentration	*Top*1	The shareholding ratio of the largest shareholder
Proportion of independent directors	*Indep*	The proportion of independent directors on the board of directors
CEO duality	*Dual*	1 if the chairman is also the CEO, 0 otherwise
Regional GDP	*GDP*	Ln (regional GDP)
Industrial structure	*Structure*3	The proportion of the tertiary industry in GDP

Source: own

(*Indep*) and CEO duality *(Dual*) are controlled. The definitions of variables are shown in Tab. 1.

3. Results

3.1 Empirical analysis

The results of descriptive statistics are presented in Tab. 2, which shows that the extreme difference in the companies' green technological innovation is 7.3639, with a standard deviation of 1.2091, indicating a significant difference in the level of green technological innovation among enterprises. The mean value of *Tre_Pos* is 0.2763, suggesting that some enterprises have taken the lead in incorporating CET; however, there is still room for further expansion of CET's coverage.

Tab. 2: Descriptive statistics

Variable	*N*	Mean	Median	SD	Min	Max
GI	31,408	0.9456	0.6931	1.2091	0.0000	7.3639
Tre	31,408	0.4172	0.0000	0.4931	0.0000	1.0000
Pos	31,408	0.6522	1.0000	0.4763	0.0000	1.0000
Tre_Pos	31,408	0.2763	0.0000	0.4472	0.0000	1.0000
Size	31,408	22.1340	21.9441	1.3223	19.7125	26.2067
Lev	31,408	0.4289	0.4239	0.2079	0.0505	0.8880
Growth	31,408	0.2128	0.1050	0.3970	−0.2963	2.4205
ROE	31,408	0.0730	0.0787	0.1243	−0.5696	0.3831
Cash	31,408	0.1904	0.1508	0.1400	0.0149	0.6911
State	31,408	0.3874	0.0000	0.4872	0.0000	1.0000
***Tobin*Q**	31,408	2.2253	1.7440	1.4802	0.9085	9.7412
***Top*1**	31,408	0.1741	0.1473	0.0908	0.1473	0.6262
Indep	31,408	0.3738	0.3333	0.0528	0.3333	0.5714
Dual	31,408	0.2677	0.0000	0.4428	0.0000	1.0000
GDP	31,408	10.4003	10.4535	0.7871	7.8546	11.7310
***Structure*3**	31,408	0.5086	0.4953	0.1204	0.3200	0.8350

Source: own

As shown in the above theoretical analysis, after China launched CET, enterprises have an incentive to enhance their level of green innovation. From the results in Tab. 3, the coefficients of *Tre_Pos* in the three columns are significantly positive, which verifies that CET helps promote green technological innovation in enterprises.

Model (2), which uses the event study method, is constructed to conduct the parallel trend test. The first period after the policy shock is selected as the benchmark group of the model and has been deleted.

$$GI_t = \alpha_0 + \alpha_1 Tre_i + \alpha_2 Pos_t + \\ + \sum_{t=1}^{5} \beta_t \, Before_t + \alpha_3 \, Current + \\ + \sum_{t=2}^{7} \gamma_t \, After_t + \varepsilon_{it} \quad (2)$$

where: $Before_t$ – the period before the policy shock; *Current* – the period of the policy shock; $After_t$ – the period after the policy shock.

As shown in Tab. 4, the green innovation levels of the treatment group and the control group exhibit the same trend before implementing CET. From the third period after the policy shock, the regression coefficients are significantly positive and show a gradually increasing

Tab. 3: Multiple regression analysis

Variable	(1)	(2)	(3)
	GI	*GI*	*GI*
Tre	0.10***	−0.05**	−0.05**
	(4.73)	(−2.07)	(−2.32)
Pos	0.39***	0.19***	0.19***
	(22.25)	(10.11)	(10.88)
Tre_Pos	0.06**	0.07***	0.07***
	(2.17)	(2.82)	(2.94)
Controls	Yes	Yes	Yes
Robust	No	No	Yes
N	31,408	31,408	31,408
R^2	0.24	0.25	0.25
F	754.73	702.31	520.22

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; *t*-values are in brackets.

Source: own

trend. It indicates that after implementing CET, the level of green innovation in the pilot areas has improved considerably compared to other areas, and the policy's impact is gradually increasing.

To prove that the conclusions are not randomly generated, we randomly select seven regions from the 31 provincial-level administrative regions in mainland China as the new treatment group, replacing the seven pilot places of CET.

Tab. 4: Parallel trend test – Part 1

Period	*GI*
Before5	−0.06
	(−1.08)
Before4	−0.01
	(−0.12)
Before3	0.05
	(1.04)
Before2	0.08
	(1.45)
Before1	0.04
	(0.82)
Current	0.05
	(0.99)

Tab. 4: Parallel trend test – Part 2

Period	*GI*
After2	0.07
	(1.32)
After3	0.21***
	(4.02)
After4	0.26***
	(5.06)
After5	0.63***
	(11.88)
After6	0.66***
	(12.72)
After7	0.09*
	(1.82)
N	31,408
R²	0.26
F	315.17

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; *t*-values are in brackets.

Source: own

The grouping dummy variable (treat) of the latest treatment group is assigned a value of 1, and all other regions are assigned a value of 0. The staged dummy variable (*period*) is still assigned with 2014 as the boundary. The control variables are the same as Model (1). Model (3) is used to perform regression analysis, repeated 500 times.

$$GI_{it} = \beta_0 + \beta_1 treat_i + \beta_2 period_t + \\ + \beta_3 treat_i \times period_t + \gamma Control_{it} + \\ + \varepsilon_{it} \quad (3)$$

where: $treat_i$ – the latest treatment group; $period_t$ – policy time.

The distribution of the estimation coefficients for the treat_period, formed by 500 random treatment groups, is shown in Figure 1. The results show a normal distribution, with a mean value close to 0. Moreover, the *p*-value of most estimates is greater than 0.1, indicating that the result is unlikely to be obtained by chance.

Considering that the inception time of CET in the seven pilot regions is not in the same year (Tab. 5), to dispel the doubt about the credibility of defining 2014 as the starting time of the policy, this study replaces Model (1) with the time-varying DID model to observe the influence of CET.

As shown in Model (4), the value of *MulPos* is assigned according to the inception time of CET in pilot regions. μ_i is the provincial fixed effect, and v_t is the time fixed effect.

$$GI_{it} = \beta_0 + \beta_1 Tre_i \times MulPos_t + \\ + \gamma Control_{it} + \mu_i + v_t + \varepsilon_{it} \quad (4)$$

where: $MulPos_t$ – inception time of CET in different regions.

The results in Tab. 6 show that the regression coefficient remains significantly positive, consistent with the main regression result. Hypothesis *H1* is confirmed again.

In China, the national CET started in the second half of 2021. As a result, there is no difference in *Tre* after 2021, which is why the study cut the sample interval to 2021. Although the sample interval guarantees the timeliness

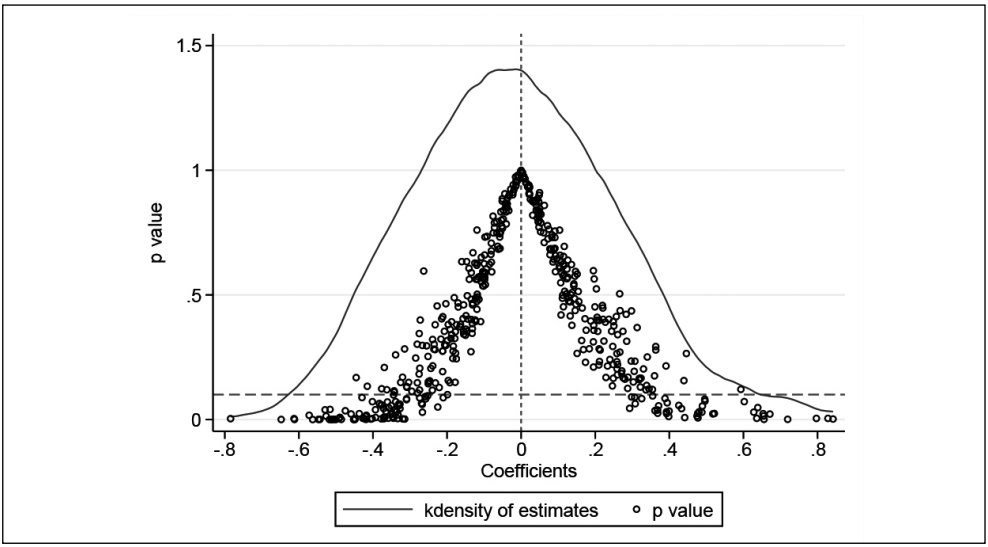

Fig. 1: **Placebo test**

Source: own

Tab. 5: **Inception time of CET in pilot regions**

Pilot regions	Beijing	Shanghai	Tianjin	Guangdong	Hubei	Chongqing	Fujian
Starting time	2013.11	2013.11	2013.12	2013.12	2014.4	2014.6	2016.12

Source: own

Tab. 6: **Replacement of the model**

Variable	(1)	(2)
	GI	*GI*
Tre_MulPos	0.05**	0.05**
	(1.96)	(2.06)
Controls	Yes	Yes
μ_i	Yes	Yes
v_t	Yes	Yes
Robust	No	Yes
N	31,408	31,408
R^2	0.28	0.28
F	221.52	181.63

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; *t*-values are in brackets.

Source: own

of the research, it may be disturbed by other policies due to the long interval. For example, since January 1, 2018, the Environmental protection tax law of the People's Republic of China has been implemented. It is China's first tax category dedicated to environmental protection, and it has played a significant role in environmental regulation. To exclude the impact of other policies during the long period, the study shortens the sample interval to 2008–2017 and uses Model (1) to make a regression. As shown in Tab. 7, the result remains robust, indicating that other policies do not alter the conclusion that CET can significantly enhance companies' green innovation, even though these policies have a combined effect on companies' green innovation alongside CET.

Tab. 7: Shorten the sample interval

Variable	(1)	(2)	(3)
	GI	*GI*	*GI*
Tre	0.11***	0.01	0.01
	(5.37)	(0.58)	(0.63)
Pos	0.19***	0.09***	0.09***
	(10.11)	(4.57)	(4.66)
Tre_Pos	0.05*	0.06**	0.06**
	(1.73)	(2.06)	(1.98)
Controls	Yes	Yes	Yes
Robust	No	No	Yes
N	21,227	21,227	21,227
R^2	0.18	0.19	0.19
F	356.68	326.25	194.01

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; *t*-values are in brackets.

Source: own

3.2 Further analysis

To pursue profit maximization goals, enterprises will fully consider the perceived costs and benefits of their decisions. Under the CET, enterprises will face different costs and benefits when choosing between purchasing carbon quotas and implementing green innovation. From a cost perspective, the price of carbon quotas may gradually increase. When enterprises choose to purchase carbon quotas, they will face higher costs. When enterprises decide to undertake green innovation, research, and development, investment becomes the primary cost, and this cost exhibits characteristics of high risk, large expenditure, and low return in the initial development stage (Xie, 2021). From the perspective of benefits, when enterprises choose to purchase carbon quotas, they will not gain income from it. When enterprises successfully implement green innovation, they no longer incur the cost of purchasing carbon quotas. They will get innovation compensation by selling surplus carbon quotas and providing technical support. However, once green innovation fails, enterprises not only fail to obtain benefits but also incur irreparable losses due to the sunk costs of research and development. Based on the above analysis, a company's cost-benefit depends not only on the price of carbon quotas but also on whether the company has the comprehensive innovation strength to realize the transformation of green innovation achievements.

Unlike administrative order environmental regulation policies, carbon quotas are marketized under the CET, and the "invisible

hand" plays a significant role in environmental protection and emission reduction. As a result, the carbon price has become a key factor affecting the cost-benefit of enterprises. The difference in carbon prices between regions affects the expected cost-benefit analysis of enterprises. The carbon price (*Cprice*) is measured as the average daily price across the seven pilot regions (Qi & Duan, 2022). Column (1) of Tab. 8 indicates that with an increase in carbon prices, enterprises will face greater cost pressure to purchase carbon quotas, leading them to adjust and improve their green innovation levels.

To promote the transformation of green innovation achievements, companies must fully consider their comprehensive innovation strength, encompassing research and development levels, human resources, technical intangible assets, and capital reserves (Cui et al., 2020). The paper selects the total factor productivity calculated by the LP method (*TFP_lp*) and the OP method (*TFP_op*) as proxies for companies' comprehensive innovation strength (Tang, 2022). As shown in Column (2) and Column (3) of Tab. 8, enterprises with prominent comprehensive innovation strength are convinced that green innovation can succeed in gaining benefits. Hence, they actively engage in green innovation activities within the context of CET to receive greater innovation compensation.

Tab. 8: The equilibrium of costs and benefits

Variable	(1)	(2)	(3)
	GI	*GI*	*GI*
Tre_Pos	0.18***	0.06**	0.09***
	(5.97)	(2.15)	(3.29)
Tre_Pos_Cprice	0.01***		
	(4.19)		
Tre_Pos_TFPlp		0.09***	
		(5.49)	
Tre_Pos_TFPop			0.03*
			(1.71)
Controls	Yes	Yes	Yes
μ_i	Yes	Yes	Yes
v_t	Yes	Yes	Yes
Robust	Yes	Yes	Yes
N	13,103	26,656	26,656
R^2	0.28	0.25	0.25
F	230.30	412.26	409.74

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; *t*-values are in brackets.

Source: own

Pollution is closely linked to people's health and life satisfaction. When carbon information is opaque, the carbon emission behavior of companies exhibits a strong externality, leading firms to lack the motivation to reduce carbon emissions and overlook green innovation. CET requires companies to disclose carbon information, including the trading volume of carbon quotas, carbon reduction measures, and the enterprise's pollution index. Mandatory disclosure alleviates the information asymmetry problem, enabling the external group

to supervise corporate carbon emission behavior effectively. To cope with the negative externality of carbon emission, external groups can change companies' pollution activities by "voting with their feet" and "voting with money" to meet their environmental protection demands (Wang & Zhao, 2018). Enterprises that purchase a large number of carbon quotas may convey negative signals, such as excessive pollution and poor social responsibility, thereby damaging their corporate reputation and performance. Therefore, due to the self-interested motivation of maintaining their reputation, enterprises are more likely to opt for green innovation rather than purchasing carbon quotas.

Media reporting has the functions of information transmission and public supervision. Enterprises that frequently report are more likely to attract the attention of the public and the administrative department. To avoid the adverse effects of negative reports, they will regulate their behavior more rigorously (Bushee et al., 2010). Media attention (*Media*) is measured by the number of newspaper and network news headlines (Song et al. 2019). Moreover, the result in Column (1) of Tab. 9 indicates that enterprises will actively enhance their green innovation level to maintain a good reputation in the face of media attention.

Analysts can also disseminate information and oversee companies by analyzing enterprise data and publishing research reports. Analysts break the information barrier between companies and external investors, thereby limiting companies' improper behaviors that could lead to reputation loss (Healy & Palepu, 2001). Analyst attention (*Analyst*) is measured by the number of analysts who have tracked the company (Yu & Fang, 2022). The coefficients in Column 2 of Tab. 9 indicate that analysts exert more regulatory pressure on companies, prompting them to undertake more green technological innovations to maintain their reputations.

It is worth further discussing whether firms will benefit from a good reputation if they undertake green innovation under CET. A good reputation has been found to foster stable and cooperative relations within enterprises. Even if adverse events impact enterprises, they can rely on a strong reputation to mitigate their effects. Therefore, enterprises with good reputations are less likely to fall into financial distress,

Tab. 9: Preserving corporate reputation

Variable	(1)	(2)
	GI	*GI*
Tre_Pos	0.07***	0.08***
	(2.78)	(2.58)
Tre_Pos_Media	0.03***	
	(2.84)	
Tre_Pos_Analyst		0.07***
		(3.62)
Controls	Yes	Yes
μ_i	Yes	Yes
v_t	Yes	Yes
Robust	Yes	Yes
N	31,408	22,971
R^2	0.25	0.27
F	472.33	368.81

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; *t*-values are in brackets.

Source: own

Tab. 10: Economic consequence

Variable	(1)	(2)
	Fincost	***Fincost***
Tre_Pos	0.01	0.02**
	(1.19)	(2.57)
Tre_Pos_GI	−0.01**	−0.01*
	(−1.99)	(−1.76)
Controls	Yes	Yes
Robust	Yes	Yes
N	30,903	30,903
R^2	0.25	0.25
F	279.28	257.10

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; *t*-values are in brackets.

Source: own

which makes creditors trust their solvency more, thereby reducing the companies' debt financing costs (Lizzeri, 1999). In the context of CET, enterprises that opt for green innovation convey a positive signal of environmental friendliness. If this signal earns a good reputation for the companies, their debt financing costs will be reduced. The debt financing cost (*Fincost*) is calculated as a proportion of the net financial expense. Tab. 10 shows that enterprises engaging in green innovation have established a good reputation and formed more stable relationships with creditors, thereby reducing debt financing costs and reaping substantial benefits from their good reputation.

The initial stage of green innovation is characterized by large investments, uncertain outcomes, and a lengthy recovery period, which means that green innovation brings enterprises more uncertain risks. Small enterprises have limited resources and face financing challenges, making it difficult for them to bear the costs and risks associated with green innovation. On the contrary, large enterprises have wider financing channels and can obtain more benefits by realizing the scale economy, which helps them to bear the cost of green innovation. Large enterprises also have sufficient resources to research and develop various green innovations, thereby hedging risk (Schumpeter, 1928). Additionally, external groups pay more attention to large enterprises (Trotman & Bradley, 1981). Enterprises will assume greater social responsibilities and make environmentally friendly decisions to maintain their reputation.

In China, enterprises with an operating income of at least 20 million yuan are categorized as either large or medium-sized enterprises. In contrast, those with lower operating incomes are classified as small or micro enterprises. The results in Tab. 11 indicate that CET primarily promotes green innovation in large and medium-sized enterprises. The conclusion reveals that the promotional effect of CET on companies' green innovation depends on the ability of different-sized enterprises to bear costs and risks, as well as the degree of concern about their reputation.

The intensity of environmental regulation faced by enterprises in different industries varies considerably. As the critical targets of environmental protection and emission reduction, the government strictly regulates enterprises in the heavily polluting industries, which are more affected by CET (Li et al., 2018). Because, for them, it is more likely to exceed the carbon quotas, which leads to higher costs and business risks. However, once heavily polluting enterprises complete their green innovations, the income will be more considerable.

Industry codes are used to categorize industries with high pollution levels. As shown in Tab. 12, CET significantly enhances the green innovation of companies with heavy pollution but has no significant impact on those with non-heavy pollution. As a result, to address

Tab. 11: Company size

Variable	(1) Large and medium enterprises	(2) Small and micro enterprises
	GI	*GI*
Tre	−0.05**	0.04
	(−1.96)	(0.75)
Pos	0.42***	0.21***
	(19.90)	(4.39)
Tre_Pos	0.05*	0.05
	(1.88)	(0.81)
Controls	Yes	Yes
N	29,813	1,096
R^2	0.15	0.09
F	363.24	7.44

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; *t*-values are in brackets.

Source: own

Tab. 12: Degree of environmental pollution

Variable	(1) Enterprises in the heavy pollution industry	(2) Enterprises in the non-heavy pollution industry
	GI	GI
Tre	−0.08	−0.04
	(−1.21)	(−1.63)
Pos	0.09**	0.22***
	(2.25)	(10.08)
Tre_Pos	0.12*	0.05*
	(1.69)	(1.65)
Controls	Yes	Yes
N	5,366	26,042
R^2	0.36	0.24
F	204.21	539.86

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; *t*-values are in brackets.

Source: own

the pollution problem caused by carbon emissions, the green innovation of enterprises in the heavily polluting industries should be given priority.

The strict implementation of CET, as a key factor in policy effectiveness, depends on supervision, disclosure, and penalties (Shen & Ma, 2012). However, due to environmental decentralization in China, local governments may overlook illegal carbon emissions by enterprises to generate fiscal revenues (Zhang, 2016). As a result, CET fails to be

effectively implemented, and its promotional effect on companies' green innovation is significantly decreased.

The number of environmental penalties reflects the enforcement of the CET. When the government punishes enterprises for violating the policy, they will feel the pressure from the huge punishment and actively respond to CET. Therefore, if the number of environmental punishment cases is not less than the median, these regions are divided into strict policy implementation groups. The results in Tab. 13 show that CET can only significantly promote companies' green innovation in regions with strict policy implementation. However, the promotion effect disappears in regions with weak policy implementation. It indicates that, in addition to relying on reasonable policy design, strict implementation of policies can fully leverage policy advantages.

Tab. 13: Policy implementation

Variable	(1) Regions with strict policy implementation	(2) Regions with weak policy implementation
	GI	*GI*
Tre	−0.08**	−0.01
	(−2.54)	(−0.27)
Pos	0.21***	0.17***
	(7.42)	(5.41)
Tre_Pos	0.08**	0.05
	(2.48)	(1.24)
Controls	Yes	Yes
N	19,334	12,074
R^2	0.28	0.21
F	488.61	218.13

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; *t*-values are in brackets.

Source: own

Conclusions

Based on the equilibrium of costs and benefits and the motivation to maintain reputation, this paper analyzes the impact of CET in China on companies' green technological innovation. It discusses its mechanism, economic consequence, and heterogeneity. The results show that: (1) CET can help to promote companies' green technological innovation. (2) Based on the equilibrium of costs and benefits, when the price of carbon quotas is higher and enterprises' total factor productivity is higher, CET has a more significant role in promoting green technological innovation. (3) Based on the motivation for reputation maintenance, when enterprises receive more media attention and analyst attention, CET significantly improves companies' green technological innovation. (4) The heterogeneity tests reveal that the promoting effect of CET on companies' green technological innovation is primarily observed in large and medium-sized enterprises, those in the heavy pollution industry, and enterprises in regions with strict policy implementation.

The conclusions of our research provide some implications. For corporates, with the improvement of CET and the accumulation of technology, more information about green innovation will flow into the market. This brings opportunities for more enterprises to complete green innovation. Managers must maintain a farsighted view to expedite the implementation of green innovation as soon as possible. For informal external supervisors, the media should help the public establish a channel to access companies' environmental information and

monitor enterprises' pollution activities. Analysts should enhance their professional competence and accurately investigate and disclose carbon information, which can impose pressure on enterprises and encourage them to undertake green technological innovation. For the Chinese government, CET in China is still in the initial stage, and there will be many problems in the implementation process in the future. Therefore, the Chinese government should strictly enforce policy implementation and encourage large enterprises to lead the way in green technological innovation while providing smaller firms with technical guidance and necessary support. For the international carbon market, the conclusions also have transferability to other economies. All governments should rationally allocate resources to maximize the regulatory effect by paying more attention to enterprises in heavily polluting industries and preventing local officials from refusing to implement policies for their self-interest. Additionally, it is worth noting that during the process of establishing CET, blind imitation should be avoided. Different economies need to tailor their national conditions and establish reasonable quota allocation methods and implementation scopes.

Finally, this study has some limitations. In the first instance, due to data limitations, our study only identifies participants in carbon emission trading at the regional level and uses seven pilot regions as the grouping standard for the difference-in-difference model. With the improvement of China's CET, more detailed information will be disclosed. Future research can employ the text mining method to accurately identify enterprises which participate in trading carbon emission quota. As a result, the grouping standard of the difference-in-difference model can be refined to the enterprise level. Moreover, this study primarily focuses on the impact of China's CET on the green technological innovation of domestic enterprises. Despite the conclusions mentioned above also having implications for the development of international carbon markets, there is a gap for further research on the international CET due to differences in quota methods and trading varieties among each carbon market. Future research can conduct in-depth comparisons of the economic consequences of different carbon emission trading policies, thereby enhancing the overall vitality and operational efficiency of the international carbon market.

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Towards sporadic demand stock management based on simulation with single reorder point estimation

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Abstract: *The goal of this paper is to decide whether bootstrapping and/or linear regression are suitable to estimate an initial reorder point in sporadic demand stock management based on past stock movement simulation (PSMS) in combination with neighborhood search-oriented optimization. Thus, we randomly generate demand data including 20–80% zero demand periods and simulate continuous review, fixed order quantity inventory control policy (R, Q) for 4 different arrangements of PSMS combined with local search (LS) with a number of bootstrapping sampling runs ranging from 5 to 500. The original idea of LS is to underestimate order lead time demand using linear regression (LR), overestimate lead time demand with the help of bootstrapping (B) and search the generated interval using PSMS to return R, Q with the optimal trade-off between inventory costs and service level. The outputs gained from simulation experiments show that avoiding the generation of overestimated reorder point with B seems to be a more sensible choice as the consumption of computational time is significantly higher than in case of LR. On the other hand, using an LR based initial reorder point may require the exploration of neighborhood in both directions, while B rather enables a more efficient one-way search as it suffers from significantly less blindness caused by PSMS compensating underestimated order lead time demand with increased replenishment orders. Furthermore, estimating just one initial reorder point brings a better opportunity to control the consumption of computational time through assigning a certain amount of computational time to every change of the initial reorder point, as a time to evaluate a single R, Q combination via PSMS is relatively stable.*

Keywords: *Supply chain management, spare parts, inventory control, sporadic demand, bootstrapping, simulation, optimization.*

JEL Classification: *M21, L62, C63.*

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Introduction

Big data techniques and their applications in inventory control are becoming increasingly popular due to the increase in data volume and the expanding use of enterprise resource planning (ERP) software. Alternative data driven

approaches such as artificial intelligence-based solutions have outperformed traditional parametric forecasting tools throughout time due to their ability to identify patterns in demand (Adam et al., 2024). However, these complex approaches frequently require significant computational assets, and they regularly need coherence with the operational capacities of companies.

In this paper, we are interested in a sporadic demand inventory control based on simulation. Sporadic demand is characteristic with a frequent occurrence of zero demand periods as well as with a high variability of non-zero demand (Yuna et al., 2023). Examples of such demand pattern can be found, e.g., in the logistics of spare parts maintaining production equipment to operate smoothly or satisfying a demand in the aftersales market (Fan et al., 2023). The first attempt to introduce a purely simulation approach to inventory management of products with sporadic demand is represented by the past stock movement simulation (PSMS) proposed by Dyntar and Kemrová (2011). PSMS represents a data driven approach that, instead of estimating order lead time demand with the help of a parametric forecasting method, focuses on a combinatorial optimization using the evolution of the replenishment process over time. Based on the outputs of simulation experiments on randomly generated sporadic demand data, Dyntar and Kemrová (2011) concluded that PSMS outperforms forecasting techniques such as single exponential smoothing or Croston's method and its modifications in trading off between holding and ordering costs and a service level. However, Hušková and Dyntar (2023) pointed out that original PSMS based on a thorough exploration of a solution space (i.e., all combinations search; AC) for a selected inventory control policy leads to an excessive consumption of computational time and potentially exclude this approach from real-life applications, mainly in situations when total non-zero demand is too high. These authors also suggest reducing the searched solution space through underestimating a minimal reorder point with the help of linear regression (LR) and overestimating a maximal reorder point using bootstrapping (B). When simulating randomly generated data with an increasing level of sporadicity and non-zero demand variability, Hušková and Dyntar (2023) showed that their approach entitled local search (LS) brings substantial savings of the computational time while maintaining a pretty decent ability to attain the optimal trade-off between the holding and ordering costs and the service level compared to PSMS + AC. Despite that we consider an initial idea of LS to be interesting, we see an additional potential to shorten the consumption of computational time in estimating just a single reorder requiring a subsequent replacement of in-depth interval search rather than with a neighborhood exploration. The goal of this paper is to decide whether the linear regression and/or the bootstrapping method used in LS are suitable to become a cornerstone in sporadic demand stock management based on simulation with a single reorder point. That is why we randomly generate demand data differing in a level of sporadicity (i.e., 20, 40, 60, and 80% zero demand periods) and simulate 4 different arrangements of PSMS + LS with the number of bootstrapping sampling runs equal to 5, 10, 100 and 500. Together with PSMS + LS, we also simulate PSMS + AC and compare the consumption of computational time and holding and ordering costs.

The rest of this article is organized as follows: first, we summarize the state-of-the-art in sporadic demand inventory control based on both parametric and non-parametric approaches. We then describe basic features of randomly generated demand data and provide a description of the arrangement of simulation experiments including a modification of PSMS + LS as a method to measure the consumption of computational time more efficiently. We subsequently present the outputs attained from simulation experiments and discuss the benefits and drawbacks of LR and B if these methods are to be used to estimate the single reorder point. Finally, we conclude the paper and set the goals for our future work.

1 Theoretical background

Effective supply chain management (SCM) is essential for enhancing organizational performance and competitive advantage in today's highly competitive global market (White & Mohdzain, 2009). SCM involves the integrated relationship between suppliers and customers, playing a pivotal role in various industries (Singh et al., 2014). One of the key challenges in SCM represents inventory management that requires careful consideration to effectively balance supply and demand. Inventory management

is considered a critical issue in efficient supply chain systems due to its substantial impact on total costs (Mkonu & Gichana, 2019).

Demand forecasting is a crucial element of inventory management, playing a pivotal role in optimizing supply chain operations. Accurate demand forecasting enables businesses to plan their resources efficiently and enhance customer satisfaction (Park et al., 2020). Any item's inventory management process starts with estimating the order lead time demand's mean and variance, after which a demand distribution is fitted to these parameters (Babai et al., 2022). Based on the mean and variance of the lead time demand, an ideal safety stock level is determined to minimize overall system costs and meet a certain availability target (Prak & Teunter, 2019). In this two-stage process, a time series forecasting method is typically used for the estimation of order lead time demand. Traditional parametric time series forecasting techniques such as single exponential smoothing (SES) are widely used in practice because they are straightforward and simple to use. They mostly rely on historical data and make little effort to determine the factors driving the need for spare parts by including contextual information. As a result, they can be easily automated using data that is readily available in ERP systems and take less work to acquire (Pinçe et al., 2021). However, the SES updating mechanism is not designed to withstand extended periods of no demand and returns poor estimations when dealing with sporadic demand as firstly pointed out by Croston (1972). Throughout the years, Croston's method and its modifications have formed the major stream of the scientific literature dealing with sporadic demand forecasting (Babai et al., 2019; Tian et al., 2021). However, these methods suffer from several drawbacks, including, for example, an assumption on a probability distribution of the demand during order lead time or a separation of forecasting from inventory control when a high forecast accuracy does not necessarily imply high inventory performance (Syntetos et al., 2010).

The disadvantages of parametric forecasting methods lead to the development of alternative non-parametric approaches. These mainly include bootstrapping (Hasni et al., 2019), empirical method (Zhu et al., 2017), machine learning (Adur Kannan et al., 2020) and neural networks (Shafi et al., 2023). In general, non-parametric approaches are more flexible and able to accommodate complex demand patterns arising, for example, as a result of maintenance policies (Pinçe et al., 2021). On the other hand, the artificial intelligence-based methods mainly represent a higher computational complexity, require substantially larger datasets and longer training times that may be impractical in real-life applications (Hasan et al., 2024).

The excessive consumption of computational time is, after all, a major issue of PSMS that is based on simulation of discrete time intervals in which a replenishment, a demand satisfaction and replenishment order placement in a pipeline can take place (Hušková et al., 2023). The simulation of the demand satisfaction and the replenishment process is for a selected inventory control policy complemented by a combinatorial optimization of a selected inventory performance measure. The inventory performance measure usually represents a trade-off curve showing the trade-off between inventory costs and attained service levels (Syntetos et al., 2015). As PSMS represents discrete-event simulation (De Sousa Junior et al., 2019), one way of shortening the computational time is decreasing the number of simulated time intervals through a demand aggregation procedure (Boylan & Babai, 2016; Rostami-Tabar et al., 2022, 2023). There is also the possibility to adopt an optimization via simulation (OvS) technique encompassing the generation of possible solution candidates for the problem, and their evaluation via simulation model (Fu, 2002). Numerous OvS techniques, including heuristics and metaheuristics, have been developed during the past few decades (Do Amaral et al., 2022), becoming a regular tool in Industry 4.0 (Santos et al., 2022). However, we still see the greatest potential in the sensitive reduction of the solution space, and that is what we will focus on in the rest of this paper.

2 Research methodology

To achieve the goals of the paper, we randomly generate demand data with different levels of sporadicity. For demand data generation, we use a two-phase process described in Hušková and Dyntar (2023). Each generated data set with 20, 40, 60, and 80% zero demand periods consists of 10,000 time series, each of 36-period length, with a non-zero demand per period (S_t) uniformly ranging from 1 to 40 pieces. Based on Syntetos et al. (2005),

we calculate the average demand interval (*ADI*) to assess the sporadicity of the time series:

$$ADI = \frac{T}{N_{S_t}} \quad (1)$$

where: N_{S_t} – number of non-zero demand periods in a time series; T – total number of periods.

Then, based on Syntetos et al. (2005), we calculate the squared coefficient of variation (CV2) to assess a variability of non-zero demand:

$$CV^2 = \left(\frac{\sigma_{St}}{\bar{S}_t}\right)^2 \quad (2)$$

where: σ_{S_t} – non-zero demand standard deviation; $\bar{S}_t$ – non-zero demand average.

Based on recommended *ADI* = 0.49 and CV^2 = 1.32 cut-off values, we apply a demand classification scheme proposed by Syntetos et al. (2005) to sort the time series into 4 different groups (i.e., smooth, erratic, intermittent and lumpy). We load demand data into PSMS + AC and also into modified PSMS + LS of continuous review, fixed order quantity inventory control policy (i.e., *R*, *Q*) in the form of MS Excel VBA code available in Hušková and Dyntar (2023). Our modification of PSMS + LS is shown in Fig. 1 and lies in a distinctive separation of minimal reorder point estimation using LR (i.e., R_{LR}), maximal reorder point estimation using B (i.e., R_B) and subsequent run of PSMS + LS for all time series in a randomly generated data set.

This arrangement enables to measure the consumption of computational time for each part of the simulation experiment individually using the MS Excel function NOW(). Together with the demand data we also load parameters including holding costs (c_h), ordering costs (c_o), required fill rate (*FR*), price (*p*) and order lead time (*LT*) to PSMS + AC/LS (Tab. 1).

In all simulation experiments we assume that backordering and placing more than one order during the lead time is prohibited.

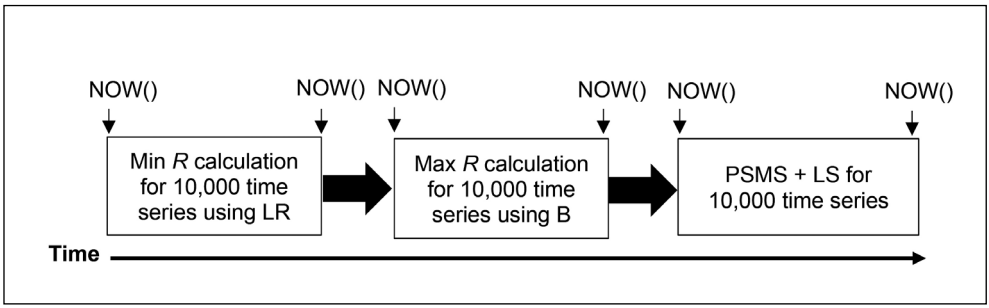

Fig. 1: **Arrangement of simulation experiments for a randomly generated demand data set**

Source: own

Tab. 1: **Simulation experiments – parameters**

Parameters	Value
c_h (% of average stock in EUR/period)	2
c_o (EUR/1 order)	18
***FR* (%)**	95
***p* (EUR/piece)**	85
***LT* (periods)**	2

Source: own

On the other hand, a partial satisfaction of a demand in a period is permitted when decreasing an attained service level in the form of fill rate. If the attained fill rate for a simulated $R < Q$ combination in a simulation experiment does not at least meet the required value, such combination is eliminated from the ensuing calculation of total holding and ordering costs (C_t) using Equation (3):

$$C_t = AI \cdot c_h \cdot p \cdot T + N_o \cdot c_o \quad (3)$$

where: AI – average inventory; N_o – number of orders.

To avoid a stock out in the very beginning of the PSMS of a time series, we also set an initial inventory (II) using Equation (4):

$$II = \sum_{t=1}^{LT+1} S_t \quad (4)$$

where: t – a period.

Combining 4 randomly generated demand data sets, each containing 10,000 time series with 1 variety of PSMS + AC and 4 varieties of PSMS + LS involving B sampling 5, 10, 100 or 500 times from a time series we carry out 4 10,000 (1 + 4) = 200,000 simulation experiments. The sample size of B was determined based on previous experiences. The low sampling numbers of 5 and 10 were set in order to show the inadequacy of this sampling. On the contrary, the high number of 100 and 500 was set for the reason of presenting the increasing consumption of time, while there will be no significant improvement of the other monitored parameters. In each experiment, we are interested in the best attained minimal total holding and ordering costs ($C_{t,best}$) represented in case of LS by a certain estimation of R_{LR} and R_B, and also by the best attained reorder point R_{LS} expected to meet $R_{LR} \leq R_{LS} \leq R_B$. In case of AC, $C_{t,best}$ represents the best possible total holding and ordering costs and, therefore, R_{AC} represents the best possible reorder point, which means that $R_{AC} \leq R_{LS}$. To perform simulation experiments, we use a computer with the processor Intel Core i7 – 2.8 GHz, 16 GB RAM and MS Excel 2016.

3 Results and discussion

Based on the demand classification scheme proposed by Syntetos et al. (2005), we sorted the generated time series into 4 groups (Tab. 2). While for 20% zero demand periods in a time series we mainly deal with smooth and marginally with erratic demand, with an increasing number of zero demand periods we switch to an intermittent demand pattern changing gradually to lumpy demand as the variability of non-zero demand grows. Moreover, while the total demand in 36 periods for 20% of zero demand time series ranges from 383 to 804 pieces with an average equal to 594 pieces, for 80% of zero demand series, it substantially decreases ranging from 39 to 250 pieces with an average of 144 pieces.

First, we record reorder points connected with the best attained minimal total holding and ordering costs (i.e., R_{AC}, R_{LS}), while for R_{LS} we further analyze related estimations of minimal and maximal reorder points arising from linear regression and bootstrapping with the different number of sampling runs (i.e., R_{LR}, R_{B_5}, R_{B_10}, R_{B_100}, R_{B_500}). To assess whether and in what extent LS fulfills its role to capture $R_{LR} \leq R_{AC} \leq R_B$, we display a distribution of reorder points (Fig. 2) and also the differences among reorder points (Δ_R) for a simulated time series in the form of percentiles (Tab. 3).

Tab. 2: Demand pattern of randomly generated data

Zero demand periods (%)	Number of time series			
	Smooth	Intermittent	Erratic	Lumpy
20	9,662	0	338	0
40	0	9,441	0	559
60	0	9,098	0	902
80	0	8,580	0	1,420

Source: own

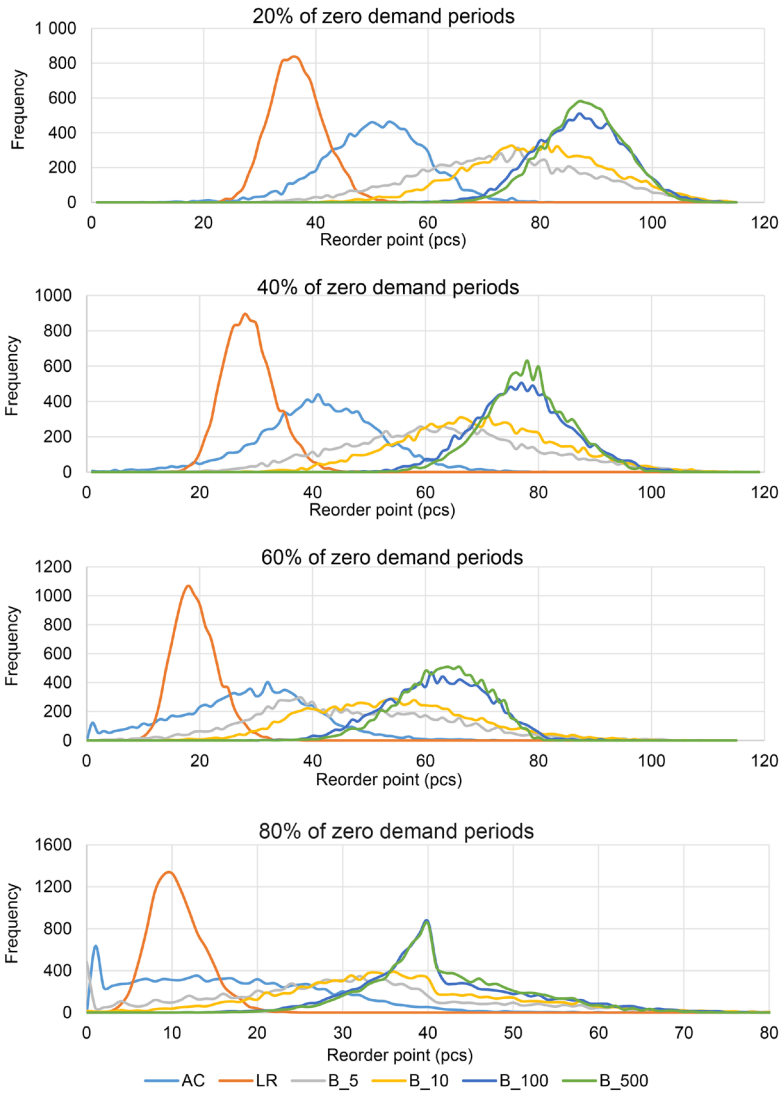

Fig. 2: Distribution of reorder points

Source: own

Tab. 3: ΔR percentiles – Part 1

Zero demand periods (%)	B runs	Δ_R percentiles (%)																	Δ_R
		0	1	2	5	10	20	30	40	50	60	70	80	90	95	98	99	100	
20	All	−45	−32	−30	−26	−24	−21	−18	−17	−15	−13	−10	−8	−4	0	4	7	27	$R_{LR} - R_{AC}$
	5	−31	−14	−9	−3	2	9	14	18	22	27	31	36	43	49	55	59	84	$R_B - R_{AC}$
		−14	4	7	13	18	25	29	33	37	40	44	49	56	60	65	68	80	$R_B - R_{LR}$
	10	−24	−2	2	7	12	18	22	25	29	32	36	40	46	51	57	60	80	$R_B - R_{AC}$
		2	16	20	24	28	33	37	40	43	46	49	53	58	62	66	69	79	$R_B - R_{LR}$
	100	0	16	19	22	25	29	31	34	36	38	41	44	48	52	57	61	86	$R_B - R_{AC}$
		23	36	37	40	42	45	47	49	51	52	54	56	59	61	64	65	72	$R_B - R_{LR}$
	500	1	19	21	25	27	30	32	34	36	38	41	44	48	52	56	59	81	$R_B - R_{AC}$
		31	39	40	42	44	47	48	50	51	53	54	55	57	59	61	62	69	$R_B - R_{LR}$
40	All	−54	−35	−32	−28	−25	−20	−18	−15	−13	−11	−8	−5	0	5	12	16	33	$R_{LR} - R_{AC}$
	5	−44	−19	−15	−8	−2	6	12	17	21	26	31	37	46	52	60	66	95	$R_B - R_{AC}$
		−25	−1	3	8	13	20	25	29	34	38	42	47	55	61	67	71	84	$R_B - R_{LR}$
	10	−27	−6	−2	3	9	15	20	24	28	32	36	41	49	55	62	68	95	$R_B - R_{AC}$
		−6	11	15	20	24	30	34	37	40	44	47	51	58	62	67	70	90	$R_B - R_{LR}$
	100	−15	11	14	19	22	26	30	33	35	38	41	45	51	55	61	67	89	$R_B - R_{AC}$
		20	32	34	37	39	42	45	46	48	50	52	54	58	61	64	66	76	$R_B - R_{LR}$
	500	−15	14	17	21	24	28	31	33	36	38	41	45	50	55	62	66	87	$R_B - R_{AC}$
		26	35	37	40	42	44	46	48	49	50	52	54	56	58	61	62	70	$R_B - R_{LR}$
60	All	−57	−35	−31	−27	−23	−18	−16	−13	−10	−7	−4	0	6	11	15	18	29	$R_{LR} - R_{AC}$
	5	−48	−24	−19	−12	−6	2	8	13	17	22	28	34	44	52	61	67	102	$R_B - R_{AC}$
		−25	−6	−3	3	8	14	18	22	26	31	36	42	49	56	65	71	92	$R_B - R_{LR}$
	10	−35	−12	−8	−1	4	11	16	21	25	29	34	40	48	54	62	68	99	$R_B - R_{AC}$
		−11	7	9	14	17	22	27	30	34	38	41	46	53	58	65	68	94	$R_B - R_{LR}$
	100	−17	5	9	14	18	23	26	29	33	36	40	44	51	56	62	66	85	$R_B - R_{AC}$
		16	25	27	30	33	36	39	41	43	45	47	49	53	55	58	60	75	$R_B - R_{LR}$
	500	−14	7	11	16	20	25	28	31	33	36	40	44	51	56	61	64	77	$R_B - R_{AC}$
		20	28	30	33	36	38	41	42	44	46	47	49	51	53	55	56	62	$R_B - R_{LR}$

Tab. 3: ΔR percentiles – Part 2

Zero demand periods (%)	B runs	Δ_R percentiles (%)																	Δ_R
		0	1	2	5	10	20	30	40	50	60	70	80	90	95	98	99	100	
80	All	−62	−32	−28	−24	−20	−16	−12	−9	−6	−3	0	3	7	9	12	14	23	$R_{LR} - R_{AC}$
	5	−58	−31	−26	−18	−10	−3	3	7	12	17	22	27	35	44	53	59	100	$R_B - R_{AC}$
		−22	−13	−11	−8	−2	6	11	15	19	22	25	30	40	47	54	59	103	$R_B - R_{LR}$
	10	−56	−18	−14	−7	−1	6	10	14	18	22	27	32	39	46	54	58	80	$R_B - R_{AC}$
		−19	−3	1	6	10	15	19	21	24	27	30	35	42	48	55	60	82	$R_B - R_{LR}$
	100	−38	−3	0	4	8	13	18	21	25	28	31	35	40	46	52	57	74	$R_B - R_{AC}$
		6	14	16	19	22	24	26	28	30	31	34	38	44	48	52	55	66	$R_B - R_{LR}$
	500	−30	−1	2	6	10	15	18	22	25	28	32	35	40	44	50	53	68	$R_B - R_{AC}$
		8	17	18	21	23	25	27	29	30	32	34	37	42	45	50	52	63	$R_B - R_{LR}$

Source: own

The distributions of overestimated reorder points arising from B show that with an increasing number of sampling runs there is a perceptible increase in kurtosis, and the ability of B to attain $R_B \geq R_{AC}$ grows for all levels of sporadicity in randomly generated demand data. More specifically, when speaking about the data set with 20% zero demand periods, 5 B sampling runs for at least 5% time series leads to undesirable reorder point underestimation of up to 31 pieces (i.e., $R_B - R_{AC} < 0$ in Tab. 3, row 4). In this particular situation, there is even less than a 1% time series, where $R_B - R_{LR} < 0$ (i.e., up to 14 pieces difference in Tab. 3, row 5), meaning a complete waste of time on the generation of R_B and R_{LR} as LS works assuming $R_B \geq R_{LR}$. If the simulation experiments are carried out, for example, with 100 B sampling runs, there are either no time series facing such problems (i.e., for the data set with 20% zero demand periods, see Tab. 3 rows 8 and 9), or there are less than 2% time series with $R_B - R_{AC} < 0$ for the data sets with 40, 60 and 80% zero demand periods with the $R_B - R_{AC}$ difference up to 38 pieces. While too low number of B sampling runs can cause serious trouble, we also see no significant benefit in increasing number of B sampling runs from 100 to 500 as the distribution of gained reorder points is very similar but, of course, at higher computational costs. Based on the outputs displayed in Fig. 2 and Tab. 3, we consider the ability of B to overestimate the demand during the order lead time period to be sufficient for at least 100 sampling runs. On the other hand, the ability of LR to underestimate lead time demand seems to work properly rather for a relatively low number of zero demand periods. While for the data set with 20% zero demand periods there are 5% time series with $R_{LR} - R_{AC} > 0$, in case of 80% of zero demand periods it increases to 30% as the distribution of R_{AC} is becoming more volatile, and with an increasing number of time series with $R_{AC} = 1$.

As for a certain number of time series, PSMS + LS returns no solution with at least the required service level (Tab. 4), we try to put it in connection with the number of B sampling runs and also with the differences among reorder points (Tab. 3).

It can be seen in Tab. 4 that the ability of PSMS + LS to at least attain a sub-optimal solution is strongly affected by the number of B sampling runs for all simulated data sets with the different number of zero demand periods. Furthermore, in case of 100 and 500 B sampling runs, where $R_B < R_{LR}$ is excluded, no solution for a time series occurs solely if $R_B < R_{AC}$. However, it does not mean that no solution is returned for all time series where $R_B < R_{AC}$ PSMS + LS as, for example, in the data set with 60% zero demand periods there are (36 – 24) = 12 time series (Tab. 4, row 12), for which PSMS + LS with 100 B sampling runs is able to compensate

Tab. 4: PSMS + LS simulation experiments returning no solution

Zero demand periods (%)	B runs	No solution	No solution for $R_B - R_{AC} < 0$	Time series with $R_B - R_{AC} < 0$
20	5	123	119	688
	10	27	27	125
	100	0	0	0
	500	0	0	0
40	5	280	261	1,115
	10	66	66	295
	100	8	8	8
	500	2	2	2
60	5	547	504	1,642
	10	142	139	575
	100	24	24	36
	500	19	19	25
80	5	1,313	1,152	2,385
	10	298	276	1,090
	100	53	53	181
	500	42	42	124

Source: own

low R_B estimation through the increased replenishment orders and thereby successfully bridge the relatively small gap between R_B and R_{AC}. Similarly, for 80% of zero demand periods there are (181 – 53) = 128 such time series (Tab. 4, row 16).

Together with the distribution of reorder points and their differences, we are also interested in the consumption of the computational time, which can be seen in Tab. 5.

For PSMS + AC, which guarantees to attain optimal trade-off between holding and ordering costs and the fill rate, the consumption of computational time decreases from 104 min for the data set with 20% zero demand periods (Tab. 5, row 2, column 6) to 6.6 min for the data set with 80% zero demand periods (Tab. 5, row 17, column 6). This is because the average total demand decreases from 594 pieces to 144 pieces leading to the substantial reduction in the number of simulated R, Q combinations. At the same time, the consumption of computational time of PSMS + LS for B with 100 sampling runs ensuring a satisfactory distribution of reorder points decreases from 36.6 min for the data set with 20% zero demand periods (Tab. 5, row 5, column 6) to 23.4 min for the data set with 80% zero demand periods (Tab. 5, row 20, column 6). Thus, for the generated intermittent-lumpy data sets with 60 and 80% zero demand periods PSMS + LS with B runs ≥ 100 returns a worse solution in term of the consumption of computational time. That is mainly because the overestimating of the reorder point itself is too time demanding slightly fluctuating, for example, in case of B with 100 sampling runs between 15.8 min and 17.3 min for all generated datasets. It is obvious that the original idea of LS can only work in situations when either the number of zero demand periods is relatively low or the non-zero demands per period in a strongly intermittent time series are high enough to make it worthwhile to consume a certain amount of fixed time on a reduction of the solution space.

Moreover, the reduction of the solution space bringing some time savings has to go

Tab. 5: Consumption of computational time

Zero demand periods (%)	AC or LS	LR (min)	B (min)	LS (min)	Total (min)	Simulated *R, Q* combinations	Time consumption of AC or LS (μs/combination)
20	AC	–	–	–	104.0	1,779,798,143	3.51
	LS with B_5	3.0	1.9	12.9	17.8	203,561,263	3.80
	LS with B_10	3.0	2.6	14.5	20.2	236,117,950	3.69
	LS with B_100	3.0	16.4	17.2	36.6	275,184,940	3.74
	LS with B_500	3.0	72.1	17.4	92.5	278,325,538	3.75
40	AC	–	–	–	60.6	1,030,911,930	3.52
	LS with B_5	3.0	1.9	9.2	14.1	141,568,777	3.88
	LS with B_10	3.0	2.7	10.8	16.5	167,930,160	3.87
	LS with B_100	3.0	16.1	12.5	31.6	197,964,333	3.79
	LS with B_500	3.1	69.9	12.7	85.6	200,834,147	3.79
60	AC	–	–	–	24.5	420,327,481	3.50
	LS with B_5	3.1	1.9	5.1	10.1	73,016,524	4.21
	LS with B_10	3.0	2.6	6.1	11.8	89,754,866	4.08
	LS with B_100	3.0	15.8	7.3	26.1	109,553,979	4.02
	LS with B_500	3.0	69.3	7.3	79.7	111,469,107	3.95
80	AC	–	–	–	6.6	106,990,712	3.72
	LS with B_5	2.9	1.9	2.2	7.1	25,219,184	5.21
	LS with B_10	3.1	3.0	2.6	8.8	31,866,715	4.97
	LS with B_100	3.1	17.3	3.1	23.4	38,640,457	4.77
	LS with B_500	3.0	75.7	3.1	81.8	39,229,716	4.72

Source: own

hand in hand with a corresponding level of holding and ordering costs. That is why, for each simulation experiment, we calculate the difference between the best attained holding and ordering costs arising from PSMS + LS and the best possible holding and ordering costs arising from PSMS + AC (i.e., $\Delta_{Ct,best}$). These differences are in the form of percentiles displayed in the following Tab. 6.

The outputs in Tab. 6 confirm the good performance of PSMS + LS with 100 bootstrapping runs for 20% and 40% of zero-demand periods in the generated datasets. More precisely, in case of 20% of zeros, the almost 68% decrease in the consumption of computational time is followed with at least a 95% success rate in attaining the best possible holding and ordering costs, while for the rest 5% time series there is an increase in these costs of no more than 30%. For 40% zeros the decrease in the consumption of computational time is almost 48%, the success rate reaches at least 90%, and for the remaining 10% time series, there is an increase in holding and ordering costs of up to 83% compared to PSMS + AC.

Conclusions

Replacing LS with further neighborhood search-oriented optimization could bring several benefits.

Tab. 6: $\Delta_{Ct,best}$ **percentiles**

Zero demand periods (%)	B runs	$\Delta_{Ct,best}$ percentiles (%)																
		0	1	2	5	10	20	30	40	50	60	70	80	90	95	98	99	100
20	5	0	0	0	0	0	0	0	0	0	0	0	0	0	6	19	33	271
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	12	91
	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	10	30
	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	10	30
40	5	0	0	0	0	0	0	0	0	0	0	0	0	7	17	33	49	222
	10	0	0	0	0	0	0	0	0	0	0	0	0	2	8	17	23	239
	100	0	0	0	0	0	0	0	0	0	0	0	0	0	7	15	20	83
	500	0	0	0	0	0	0	0	0	0	0	0	0	0	7	15	20	83
60	5	0	0	0	0	0	0	0	0	0	0	0	6	17	29	48	64	224
	10	0	0	0	0	0	0	0	0	0	0	0	2	11	20	35	43	197
	100	0	0	0	0	0	0	0	0	0	0	0	0	9	17	29	38	178
	500	0	0	0	0	0	0	0	0	0	0	0	0	9	17	29	38	178
80	5	0	0	0	0	0	0	0	0	0	0	4	11	25	43	66	87	323
	10	0	0	0	0	0	0	0	0	0	0	2	9	21	38	62	83	309
	100	0	0	0	0	0	0	0	0	0	0	0	6	18	32	54	71	262
	500	0	0	0	0	0	0	0	0	0	0	0	6	18	32	53	71	262

Source: own

First, there is a potential to extend the application area of PSMS on time series with a higher number of zero demand periods through additional savings of the computational time arising from the generation of just one reorder point. From this perspective, avoiding the generation of an overestimated reorder point with bootstrapping seems to be a sensible choice. On the other hand, using an LR based reorder point may require the neighborhood exploration in both directions, as with increasing sporadicity there is also an increase in probability that $R_{LR} \geq R_{AC}$ forcing PSMS to return at least a sub-optimal solution, and for an initial $R_{LR} < R_{AC}$ there is a risk of PSMS returning an at least sub-optimal solution through increased replenishment orders. Potentially, that brings a time loss as one direction of the search is always not promising. On the contrary, using bootstrapping with a reasonable number of sampling runs rather enables application of a more efficient one-way search as, for the vast majority of cases, an initial value of $R_B \geq R_{AC}$ forcing PSMS to return at least a sub-optimal solution, and for the remaining small number of initial estimations of $R_B < R_{AC}$, there is a high probability of PSMS returning no solution. Thus, bootstrapping suffers from significantly less blindness compared to linear regression.

Second, estimating just one initial reorder point brings a better opportunity to control the consumption of computational time. While for PSMS + AC we examine $\frac{S\cdot(S-1)}{2}$ combinations of $R < Q$ where $S = \sum_{t=1}^{T} S_t$ represents the total demand known before executing the simulation-optimization itself, to evaluate the number of examined R, Q combinations for PSMS + LS is quite complicated and at least requires spending a fixed time on R_{LR} and R_B generation. For the single reorder point, on the other hand, the fixed time is reduced and, based on the preferences, some additional time is spent on a one or two-way neighborhood search simply assigning a certain amount of computational time to every change of the initial reorder point, as a time to evaluate a single R, Q combination via PSMS is relatively

stable. The neighborhood search can also be combined with the efficient discretization of solution space proposed by Hušková et al. (2023) when the available additional time is scarce.

The ability of bootstrapping to overestimate order lead time demand quite reliably brings an inspiration for our future work. Although decreasing the number of sampling runs affects the consumption of computational time of bootstrapping positively, it potentially leads to a poor representation of reorder point. Thus, rather than decreasing the number of sampling runs, we see potential in simplifying the sampling process through the application of an empirical method originally proposed by Porras and Decker (2008). The empirical method avoids repetitive sampling, which is the essential component of bootstrapping and facilitates fast generation of a lead time demand distribution directly from a time series (Van Wingerden et al., 2014). The difference between bootstrapping and empirical method is shown in Fig. 3.

While for bootstrapping a sampling run consists of randomly chosen demands from a time series according to lead time, the empirical method rather gradually sums up these demands. It means that the empirical method does not require determination of the number of sampling runs. On the other hand, there is a potential lack of values for the determination of reorder point with the corresponding quality if a time series is too short or if the lead

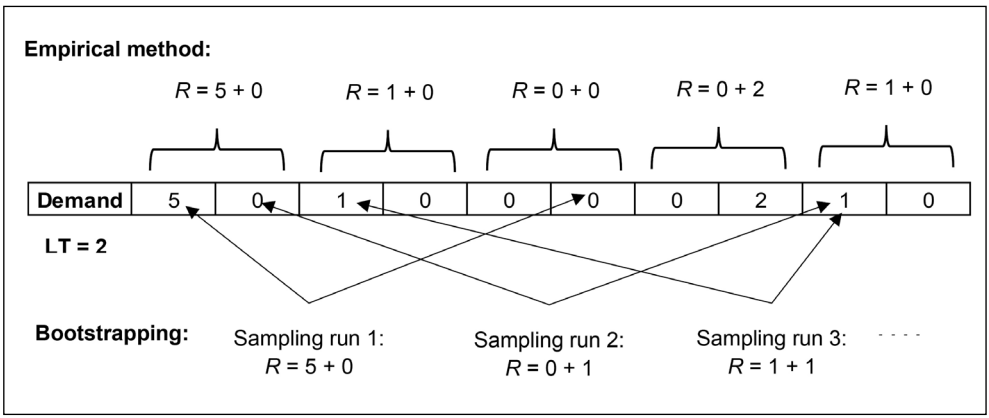

Fig. 3: Difference between bootstrapping and empirical method

Source: own

time is too long. To decide whether the empirical method can replace bootstrapping represents another challenge for our future work.

In conclusion, it could be said that the results of the simulation experiments bring further improvement of the compromise between the minimum ordering and holding costs, required fill rate and the consumption of computing time. This means that the proposed method becomes a further step more applicable in real daily inventory control tasks that show characteristics of sporadic demand. One of the next steps of our research is also the verification of the algorithm on real data to confirm the success of the proposed method within real tasks.

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Does digital transformation propel innovation strategies? An empirical investigation based on machine learning and the dynamic GMM approach

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Abstract: *In today's digital landscape, the transformation through digital technologies is revolutionizing traditional business models and innovation practices. Numerous organizations are accelerating their digital transformation efforts to enhance manufacturing capabilities, operational efficiency, and competitive advantage. While the significant role of digital transformation in economic development has been widely recognized in academic literature, research exploring the complex interplay between digital transformation and innovation strategies remains limited. This study aims to explore this relationship by utilizing annual report data and patent information from Chinese listed companies over the period from 2012 to 2021. Our findings indicate that digital transformation has a positive impact on both R&D input strategies and innovation output strategies. Specifically, it increases firms' propensity to invest in R&D activities, thereby increasing potential future innovation returns. Moreover, digital transformation bolsters both strategic and substantive innovation by leveraging digital capabilities for better resource integration. This paper significantly contributes to the existing literature on digital transformation and innovation strategies, offering valuable insights that can facilitate higher levels of digital transformation and promote high-quality economic development.*

Keywords: *Digital transformation, innovation strategies, R&D change, R&D growth, substantive innovation, strategic innovation.*

JEL Classification: *G34, O31, O32, O33.*

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Introduction

As emerging digital technologies rapidly integrate with traditional industries, it is imperative to consider the strategic impact of digital technologies on micro-level enterprises. The adoption of modern digital technologies, such as artificial intelligence, blockchain, cloud computing, and big data, has accelerated the digital transformation phenomenon within the corporate sector (Peng & Changqi, 2022; Tian et al., 2022; Tu & He, 2022). Firms now recognize the crucial importance of digital transformation as it disrupts traditional business models and innovation methods (Loonam

et al., 2018). Existing research in the economic branches of digital transformation has already demonstrated its potential to stimulate product innovation, enhance operational efficiency, and improve economic outlooks (e.g., Hess et al., 2020; Reuschl et al., 2022; Verhoef et al., 2021). As a result, the impact of digital transformation on strategic shifts within firms has garnered increasing attention from economists and policymakers.

Innovation strategy refers to a proactive approach by firms to continuously engage in research and development across various dimensions such as business strategy, processes, technology, products, and organizational structures, thereby maintaining a unique competitive advantage in a dynamic environment (Ma & Zhu, 2022; Müller et al., 2021; Zhang et al., 2022). In essence, an innovation strategy guides firms in navigating survival and growth in rapidly changing markets, ensuring sustained competitiveness and long-term development. However, assessing innovation solely based on R&D and patent activities limits a comprehensive understanding of actual technological or innovation advancements (Wang et al., 2022). Conversely, despite a strategic surge in innovation quantity, a decline in substantial innovation can hinder an innovation-driven economic transformation due to limited innovation resources (Hu et al., 2020; Ma & Zhu, 2022). Given that digital transformation introduces new technological paradigms and catalyzes profound changes in production methods and governance, exploring the unverified relationship between digital transformation and multidimensional innovation strategies holds significant economic value.

This study seeks to fill the research gap by analyzing how digital transformation influences multidimensional innovation strategies in the context of China. As the world's second-largest contributor to the digital economy, China offers a distinctive and dynamic context for this investigation, with its digital economy reaching a remarkable size of 39.2 trillion yuan (approximately USD 5.4 trillion), accounting for 38.6% of the national GDP (Tian et al., 2022). For example, Huawei and Alibaba are exemplary cases of digital transformation in China. Huawei has driven significant advancements in 5G and cloud computing, contributing extensively to the development of digital infrastructure both domestically and internationally. Similarly, Alibaba has revolutionized e-commerce and digital finance by leveraging big data and artificial intelligence to innovate in areas such as logistics, digital payments, and retail. These companies illustrate the substantial role of digital transformation in reshaping China's economic landscape. This significant market size provides a rich data sample for our research. This paper seeks to answer the following questions: (1) Can digital transformation drive innovation strategies? (2) If so, which sub-dimensions of innovation strategy are influenced by digital transformation?

Using a sample of 3,920 publicly listed Chinese companies from 2012 to 2021, we examined the effect of digital transformation on corporate-level innovation strategies. We categorized innovation strategies into input strategies and output strategies for comprehensive analysis. According to Caballero-Morales (2021), innovation is a crucial process that involves developing value-added features in products to command a premium price, necessitating the analysis of innovation strategies within firms' production processes prior to standardization. Key components include internal R&D and the acquisition of innovative information from external sources. When these are combined with employee skills and capabilities, they enhance the performance of knowledge output (Zahra & George, 2002). Consequently, we measured innovation input strategies through R&D intensity and growth, while differentiating between strategic and substantive innovation for output strategies. To address the dynamic and persistent nature of innovation strategies, we utilized the generalized method of moments (GMM) estimation technique. Our results demonstrate that digital transformation positively impacts all four dimensions of corporate innovation strategies.

Our paper makes several significant contributions. First, it utilizes machine learning-based text mining techniques to develop a comprehensive digital transformation index for firms, derived from information in their annual reports. By employing the unsupervised machine learning algorithm Word2vec, a deep learning approach, we enhance traditional text analysis methods. This enhancement is achieved through training models on the entire dataset and calculating word vector similarities, thereby more effectively capturing the level of digital transformation within firms. Second, innovation

strategy research often faces endogeneity issues due to reverse causality and omitted variable bias. Our study demonstrates, through the use of the GMM model, that corporate R&D investment and innovation outputs are dynamic processes. The robustness of results from within-group parameter tests effectively captures the intrinsic dynamics of innovation strategies. Compared to traditional estimation techniques, our approach offers more reliable and unbiased parameter estimates in this field. Third, we identify and examine the factors of digital transformation that influence multidimensional innovation strategies, thus expanding the understanding of the economic effects and mechanisms of digital transformation. This exploration enhances the comprehension of factors affecting multidimensional innovation strategies and provides valuable insights for formulating targeted policies.

The structure of this paper is organized as follows. Section 1 introduces the main theoretical and empirical issues. Section 2 outlines the research design, detailing the data, variables, and empirical models. Section 3 presents the empirical findings, including robustness checks and discussion. Finally, Section 4 draws the conclusions.

1 Theoretical background and hypothesis development

For firms focused on optimizing production processes and reshaping organizational business models, digital transformation has increasingly become a focal point (Baiyere et al., 2020). This process involves incorporating advanced digital technologies, including artificial intelligence, blockchain, cloud computing, and big data, into various operational aspects (Sun et al., 2022). This transformation compels organizations to innovate and adapt their products, services, and operations by leveraging digital tools to enhance business processes. For example, Vial (2019) defines digital transformation as organizational adjustments in response to environmental shifts, enhancing product value through technologies like mobile computing, artificial intelligence, and cloud computing. Similarly, Hess et al. (2020) and Gong and Ribière (2021) describe digital transformation as the integration of cutting-edge technologies, marking a significant shift driven by digital advancements that enable new value creation opportunities. Furthermore, Verhoef et al. (2021) delineate the digital transformation process into three stages: digitizing analog information, adjusting business processes through digital technologies, and strategically reshaping the operational business model. These transformations often re-envision business models, processes, and organizational cultures to fully exploit digitalization's potential in driving enterprise innovation strategies (Zhuo & Chen, 2023).

In exploring the economic impacts of digital transformation, research has primarily focused on its effects on production and operations. A central perspective argues that digital technologies enable firms to overcome internal resource and capability constraints, facilitating the use of external resources for strategic expansion into new markets and product development (Chan et al., 2018). Scholars assert that organizations can optimize production processes through digital transformation by leveraging consumer data (Earley, 2014), restructuring organizational frameworks (Kretschmer & Khashabi, 2020), and adapting value creation approaches (Rachinger et al., 2019). Moreover, digital transformation enhances organizational connectivity and collaboration within supply chains (Reuschl et al., 2022), thereby promoting operational efficiency, value creation, and innovation through ecosystem and platform utilization (Chan et al., 2018; Gong & Ribière, 2021; Rachinger et al., 2019).

In developing economies, Commander et al. (2011) observed that investments in digital technologies, such as information and communication technology, can enhance firm productivity by restructuring workplaces, thereby enabling more decentralized decision-making processes. Correspondingly, similar conclusions emerge from studies conducted in developed economies. For instance, Brynjolfsson and Hitt (2003) identified complementary effects between skilled labor and organizational innovation in sampled U.S. firms, facilitated by investments in information and communication technology. In a European context, Andersson et al. (2021) conducted a robust survey of 4,598 companies engaged in digital software development in Sweden from 2016 to 2018, finding that digitally transformed firms actively involved in software development exhibited higher rates of innovation adoption and increased sales derived from innovative activities. Additionally, Ionascu et al. (2022) examined the digital transformation of European listed

companies within the framework of the European Green Deal. Their analysis indicated that the adoption of "smart" technologies facilitates the efficient use of resources and reduces pollution, allowing companies to transition towards more sustainable business models within a circular economy. The findings emphasize that digitalization efforts are increasingly recognized and rewarded by investors, as companies embracing digital transformation and sustainable practices tend to attract more capital. Furthermore, Coco et al. (2023) investigated how 74 Italian micro, small, and medium-sized enterprises (MSMEs) effectively address the challenges of digital transformation through open innovation and design thinking techniques. This study focused on MSMEs participating in an Industry 4.0 adoption initiative, identifying key factors that drive the digitization process within these organizations. The authors underscored the significance of training, networking, and co-creation initiatives in enhancing the digital literacy of small enterprises, thereby promoting the adoption of new technologies and the advancement of innovation strategies.

Innovation strategies are crucial for evaluating the effectiveness and impact of organizations' introductions of new products, services, or processes (Sethi & Sethi, 2009). These strategies encompass dimensions like uniqueness, market competitiveness, and customer satisfaction (Tidd & Bessant, 2018). Despite this, the nexus between various aspects of digital transformation and innovation strategies remains underexplored. Indeed, exploring the relationship between digital transformation and innovation strategies within established theoretical frameworks, such as agency theory (Eisenhardt, 1989) and resource dependence theory (Salancik & Pfeffer, 1978), provides insights into agency costs arising from principal-agent divergence of interests and organizational needs for survival by extracting resources from the environment, thereby achieving interdependence and interaction.

From a standpoint grounded in agency theory, the adoption of digital transformation mitigates the challenge of insufficient innovation investment within organizations by alleviating information asymmetry between managers and shareholders. Managers oversee daily innovation activities and disclose financial data, including investments in innovation (Iqbal et al., 2020). Shareholders, however, often face information gaps, leading to asymmetry and potential conflicts (O'Connor & Rafferty, 2012). Moreover, due to the high-risk nature of innovation, managers may prioritize short-term gains over long-term investment, impacting immediate income and reputational concerns (Chen & Huang, 2023; Yuan & Wen, 2018). Concurrently, advancements in digital technologies such as big data, cloud computing, and blockchain have revolutionized financial information disclosure, enhanced transmission efficiency and ensuring broader dissemination (Cong & He, 2019). Through digital transformation, organizations enhance transparency in innovation input, improving timeliness and openness in research and development (R&D) disclosures (Zhuo & Chen, 2023). This mitigates the risk of managers providing inaccurate or delayed information to shareholders and the board (Ferreira et al., 2019; Iqbal et al., 2020; Peng & Chang-Qi, 2022). Additionally, leveraging new digital technologies automates financial data processing, reducing managerial discretion in R&D investment and ensuring innovation's financial sustainability (Llopis-Albert & Rubio, 2021).

Under the framework of resource dependence theory, digital transformation enhances innovation outputs by reshaping internal resource allocation and reducing reliance on traditional, inefficient platforms (Ferreira et al., 2019; Rachinger et al., 2019; Şimşek et al., 2019). This transformation streamlines organizational processes, improving operational efficiency in innovation activities. Furthermore, digital technologies facilitate interactive management across firms and stakeholders within innovation networks, bridging knowledge gaps with external social networks (Goldfarb & Tucker, 2019; Şimşek et al., 2019) and enhancing innovation outcomes. Moreover, digital tools improve decision-making efficiency in complex innovation strategies (Guo et al., 2022; Peng & Chang-Qi, 2022), allowing firms to establish strategic partnerships and alliances, thereby reducing dependence on single suppliers (Ferreira et al., 2019; Srinivasan & Venkatraman, 2017). This fosters knowledge exchange, resource sharing, and collaborative innovation, ultimately enhancing internal efficiency in innovation activities (Gupta et al., 2022; Llopis-Albert & Rubio, 2021; Ma & Zhu, 2022).

In conclusion, digital transformation signifies a fundamental change in how organizations

approach innovation, transcending conventional organizational constraints, mitigating information asymmetry, facilitating the rapid exchange of resources among enterprises, and presenting unprecedented opportunities for firms to advance innovation strategies through digitalization. This research endeavors to investigate the impact of digital transformation on corporate innovation strategies, thereby enriching our comprehension of the nexus between digitization and innovation within modern business landscapes. Drawing upon these discussions, we present the following hypotheses for further examination.

H1: Ceteris paribus, digital transformation exerts a positive influence on innovation strategies within firms.

2 Research methodology

2.1 Data and sample

Our research utilized a dataset of all Chinese A-share listed companies from 2012 to 2021. Financial data were obtained from the China Stock Market & Accounting Research Database, and digital transformation-related terms were extracted from annual reports. Patent information was retrieved from the Chinese Research Data Services Database. The preprocessing of data involved several steps: (1) financial firms were excluded due to their distinct governance and performance characteristics relative to non-financial firms; (2) to avoid anomalies, companies classified as "special treatment" ("ST") – those with consecutive losses over two years and at risk of delisting – were excluded from the dataset; (3) samples with missing data were removed to enhance data integrity and mitigate the impact of missing values on the analysis; (4) continuous variables were winsorized at the 1st and 99th percentiles to mitigate the impact of outliers. Following these criteria, our final dataset consisted of 27,163 firm-year observations, representing a non-balanced panel of 3,920 unique firms. This sample encompasses 82.23% of all A-share listed companies during the study period, thereby providing a comprehensive representation of the corporate landscape. Detailed information on the sample selection process is presented in Tab. 1.

Tab. 1: Sample filtering procedure

Category	Observations	Firms	Percentage (%)
Original sample	33,666	4,767	100.00
Exclusions: financial firms	753	124	2.60
Exclusions: "ST" firms	825	132	2.77
Exclusions: missing information	4,925	591	12.40
Final sample	27,163	3,920	82.23

Note: The table presents an overview of the sampling process carried out from 2012 to 2021; ST – special treatment.

Source: own

Tab. 2 presents the annual distribution of firms engaging in digital transformation, as indicated by a binary variable, throughout the sample period. The data reveal that the proportion of firms implementing digital transformation was lowest in 2012, at roughly 34.37%, and reached its highest level in 2020, at nearly 79.69%. This trend highlights a steady increase in the adoption of digital transformation practices among firms over the observed period.

2.2 Variable measurements

(1) Dependent variable. We identified two aspects of corporate innovation strategies: input strategy and output strategy. On the input side, firms can invest in R&D activities to boost their future innovation returns or adjust their innovation expenditures. Following Guo et al. (2019), we use a continuous variable (RDC), R&D change level (the ratio of current year's R&D expenditure to total assets), and a binary variable (RDG), R&D growth (equal to 1 if the firm's R&D expenditure is higher than the previous year, and 0 otherwise), to measure changes in R&D growth. On the output side, we classified the granted patents of sample firms

Tab. 2: Yearly breakdown of sample data

Observation year	Overall count	Dummy (DT) = 0	Dummy (DT) = 1	Percentage (%)
2012	1,964	1,282	682	34.73
2013	2,109	1,216	893	42.34
2014	2,163	1,017	1,146	52.98
2015	2,272	840	1,432	63.03
2016	2,443	817	1,626	66.56
2017	2,719	805	1,914	70.39
2018	3,089	856	2,233	72.29
2019	3,160	794	2,366	74.87
2020	3,324	675	2,649	79.69
2021	3,920	855	3,065	78.19
Total	27,163	9,157	18,006	66.29

Note: This table summarizes the yearly distribution of the sample data, showcasing the transition of firms towards digital transformation during the period 2012–2021.

Source: own

into three categories: invention patents, utility model patents, and design patents. In China, invention patents must meet the requirements of "novelty, inventiveness, and practical applicability" to pass the examination. In contrast, design or utility patents only require the absence of similar prior applications. Drawing on the approach of Jiang and Bai (2022), we further categorized the number of invention patents as substantive innovation (SUI), while the total number of utility model and design patents was classified as strategic innovation (STI).

(2) Independent variable. The primary independent variable in our study is digital transformation (DT). Annual reports typically encompass a company's strategic objectives, vision, and mission statements. As a significant trend in the current business landscape, the detailed articulation of digital strategies in annual reports reflects a company's commitment to and emphasis on future development. In fact, annual reports provide critical insights into corporate strategic priorities and future directions, making text analysis a vital tool for understanding strategic orientation (Kindermann et al., 2021). Distinct from merely establishing digitalization goals, we focus on technology-driven organizational processes, emphasizing digital transformation at the corporate level, as articulated in the companies' annual reports. However, in the context of the Chinese language, the same concept can be expressed in various ways, and relying solely on the frequency of individual words to represent digital transformation may result in significant information loss. To ensure the extraction of as much relevant information as possible from company annual reports, we utilized a Python-based web scraping tool to train a neural network-based Word2Vec model to expand the vocabulary related to digital transformation.

First, we segmented the management discussion and analysis (MD&A) sections of annual reports from 2012 to 2021 into lists of sentences and input layers, identifying initial keywords such as "artificial intelligence," "cloud computing," "blockchain," "big data," and "digital technology application." Second, we then used Python's Jieba, Gensim, and Re modules to extract text from these reports and applied continuous bag-of-words (CBOW) and skip-gram (SG) neural network adaptive methods (Rong, 2014), training the model with negative sampling. This process involved tokenization and stop-word removal to build a research corpus. The Word2Vec model was subsequently applied to this corpus to generate word vectors and compute word similarities, thereby identifying terms semantically related to the initial keywords. Finally, we used the generated seed

Tab. 3: Keywords of digital transformation

Dimension	Keywords
Artificial intelligence (AI)	Artificial intelligence, intelligent robotics, face recognition, deep learning, image understanding, machine learning, natural language processing, investment decision aids, intelligent data analysis, semantic search, biometrics, voice recognition, identity verification, autonomous driving, business intelligence
Blockchain (BC)	Blockchain, differential privacy technologies, smart financial contracts, digital currency, distributed computing
Cloud computing (CC)	Cloud computing, converged architecture, EB-class storage, cognitive computing, brain-like computing, billion concurrency, graph computing, in-memory computing, multiparty secure computing, green computing, internet of things, information physical systems, streaming computing
Big data (BD)	Big data, text mining, data visualization, credit reporting, mixed reality, virtual reality, data mining, heterogeneous data, augmented reality
Digital technology application (DTA)	B2B, B2C, C2B, C2C, O2O, internet finance, e-commerce, mobile internet, internet healthcare, fintech, mobile payment, smart customer service, smart marketing, quantitative finance, NFC payment, mobile internet, smart energy, smart wearing, smart agriculture, smart transportation, smart healthcare, smart home, smart investment, smart tourism, third-party, payment, smart environmental protection, smart grid, unmanned retail, digital finance, financial technology, open banking, industrial internet, netlink, digital marketing

Source: own

dictionary to calculate the frequency of these digital transformation-related keywords within each company (Tab. 3). These frequencies were then log-transformed (LN (keyword frequency + 1)) to measure the extent of digital transformation across all samples.

(3) Control variables. Drawing from the literature on finance and innovation (e.g., Choi et al., 2011; Hou et al., 2017; Hu et al., 2020; Yuan & Wen, 2018; Zhang et al., 2022), we accounted for a comprehensive array of firm and industry characteristics that could potentially influence corporate innovation strategies. The typical control variables in this study are as follows: firm size (FS), measured by the natural logarithm of total assets; firm age (FA), indicated by the natural logarithm of the number of years since establishment plus one; financial leverage (LEV), defined as the ratio of total debts to total assets; return on assets (ROA), calculated as net income divided by total assets; sales growth (SG), represented by the change in operating income relative to the previous year; board size (BS), given by the natural logarithm of the number of directors on the board; ownership concentration (OC), the proportion of shares held by the largest shareholder; and institutional ownership (IO), the ratio of shares held by institutional investors to the total number of shares.

2.3 Regression model

When studying firms' innovation strategies such as R&D investment and innovation output, employing GMM offers significant advantages. GMM serves as a robust panel data analysis technique that effectively addresses the complexities and challenges inherent in research on innovation investment. Initially, innovation investment involves firms making decisions across different time periods and market environments, and GMM leverages the temporal variation in panel data to capture the underlying dynamic processes (Arellano & Bond, 1991; Blundell & Bond, 1998). Furthermore, the input and output of innovation are often influenced by reverse causality effects (e.g., Iqbal et al., 2020; Pu & Zulkafli, 2024), where innovation strategies may simultaneously affect decisions on digital transformation. GMM mitigates endogeneity issues by introducing instrumental variables, thereby enhancing the accuracy and credibility of research findings. Moreover, GMM methodology accommodates heterogeneity in both individual and time effects, allowing the model to incorporate variations in firm

characteristics, industry attributes, and market conditions that potentially impact innovation investment. Finally, GMM's flexibility in data handling enables adaptation to diverse data structures and research designs, facilitating in-depth analysis of the dynamic characteristics and long-term effects of innovation strategies. Che et al. (2013) highlighted the weak instrument problem associated with difference GMM, underscoring the superior efficiency of system GMM over difference GMM. In this study, we employ two-step system GMM for estimation purposes. The following dynamic models are employed to examine the relationship between digital transformation and innovation strategies.

$$IS_{i,t} = \alpha_0 + \beta IS_{i,t-1} + \gamma DT_{i,t} + \\ + \delta Controls_{i,t} + \eta_i + \mu_t + \varepsilon_{i,t} \quad (1)$$

where: $IS_{i,t}$ represents the innovation strategies of firm *i* in year *t*. The lagged values of this variable are included as regressors to capture the persistence of innovation strategies. The primary variable of interest, $DT_{i,t}$ is the level of digital transformation of firm *i* in year *t*. Thus, γ measures the effect of digital transformation on innovation strategies. $Controls_{i,t}$ is the vector of control variables. α_0 represents the intercept of the equation, η_i denotes the set of firm dummies, μ_t denotes the year fixed effects, and $\varepsilon_{i,t}$ is the error term.

3 Results and discussion

3.1 Descriptive statistics

Tab. 4 presents summary statistics for four key variables of innovation strategies analyzed in our study: (1) research and development change (RDC): this variable measures the proportion of R&D expenditure relative to total assets. The mean value of RDC is 0.020, with a standard deviation of 0.020, indicating considerable variation among firms. The minimum value is 0, and the maximum value is 0.101, suggesting that some firms do not invest in R&D, while others allocate up to 10.1% of their total assets to R&D; (2) research and development growth (RDG): this binary variable indicates whether a firm's R&D expenditure increased from the previous year. The mean value of RDG is 0.540, implying that on average, 54% of the firm's experienced growth in their R&D expenditure during the sample

Tab. 4: Descriptive statistics of main variables

Variables	Observations	Mean	Std. dev.	Min	Max
RDC	27,163	0.020	0.020	0.000	0.101
RDG	27,163	0.540	0.498	0.000	1.000
SUI	27,163	1.863	1.532	0.000	5.974
STI	27,163	2.107	1.662	0.000	6.073
DT	27,163	1.415	1.388	0.000	5.056
FS	27,163	22.267	1.293	19.814	26.153
FA	27,163	2.921	0.319	1.609	3.497
LEV	27,163	0.422	0.203	0.050	0.893
ROA	27,163	0.041	0.063	−0.239	0.222
SG	27,163	0.170	0.390	−0.544	2.445
BS	27,163	2.122	0.198	1.609	2.708
OC	27,163	34.206	14.810	8.630	74.180
IO	27,163	44.383	25.029	0.321	94.529

Note: *RDC* – research and development change; *RDG* – research and development growth; *SUI* – substantial innovation; *STI* – strategic innovation; *DT* – digital transformation; *FS* – firm size; *FA* – firm age; *LEV* – financial leverage; *ROA* – return on assets; *SG* – sale growth; *BS* – board size; *OC* – ownership concentration; *IO* – institutional ownership.

Source: own

period. The standard deviation of 0.498 indicates a nearly equal split between firms that increased their R&D spending and those that did not; (3) substantial innovation (SUI): this variable captures the extent of substantial innovation within firms, measured by the number of substantial patents (such as invention patents) granted. The mean value of SUI is 1.863, with a standard deviation of 1.532, suggesting significant variability in firms' substantial innovation outputs. The minimum value is 0, indicating no substantial innovation in some firms, while the maximum value is 5.974; (4) strategic innovation (STI): this variable measures the extent of strategic innovation, defined by the number of strategic patents (such as utility model and design patents) granted. The mean value of STI is 2.107, with a standard deviation of 1.662. Similar to SUI, the minimum value of 0 indicates no strategic innovation in some firms, while the maximum value is 6.073, reflecting a wide range in strategic innovation output among our sample firms.

For digital transformation (DT), the logarithmic transformation ranges from 0 to 5.056, with a mean of 1.415. This indicates that although the maximum frequency of digital transformation-related terms in the annual reports of the sampled firms reaches up to 156 instances, the overall level of DT remains relatively moderate. Descriptive statistics for the other variables are consistent with existing literature and empirical findings (e.g., Yuan & Wen, 2018; Zhang et al., 2022).

3.2 Empirical results

While suboptimal weighting matrices do not affect the consistency of parameter estimates (the first moment of estimates), they may bias statistics related to their second moments. Therefore, prior to employing two-step system GMM estimates, we conducted within-group parameter tests using pooled ordinary least squares (POLS) and fixed effects models (FEM) for lagged dependent variables. As noted by Bond (2002), POLS introduces an upward bias in dynamic regression models due to unobserved heterogeneity and positive correlation between lagged dependent variables and error terms. Conversely, FEM in dynamic regression models exhibits a downward bias owing to the negative correlation between transformed lagged dependent variables and transformed error terms. In other words, GMM estimates of coefficients for lagged dependent variables should fall between those from FEM (downward bias) and POLS (upward bias).

Panel A of Tab. 5 presents the relationship between digital transformation and Innovative input strategies. Columns (1), (2), (4), and (5) provide POLS estimates and FEM calculations for lagged dependent variables (L.RDC and L.RDG), yielding intervals of (0.5162 to 0.9358) and (0.5967 to 0.8956), respectively. Columns (3) and (6) indicate GMM-calculated coefficients for L.RDC and L.RDG are 0.7418 and 0.7429, respectively, falling between FEM (downward bias) and POLS (upward bias), underscoring GMM's accuracy in panel system estimation of dynamic innovation strategy models. Similarly, coefficients for lagged dependent variables (L.SUI and L.STI) in Panel B of Tab. 5 also fall within intervals derived from POLS estimates and FEM calculations. In accordance with Roodman (2009), we reduced the instrument matrix to manage the number of instruments and avoid model overfitting. Additionally, only one lagged dependent variable was used as an instrument. Throughout all specifications, lagged dependent variables were considered predetermined, while all control variables were treated as endogenous, excluding the year dummy instruments. Diagnostic tests for dynamic panel GMM showed satisfactory outcomes. Specifically, we assessed autocorrelation by formulating the following null and alternative hypotheses: for first-order autocorrelation (AR1), the null hypothesis (*H0*: no first-order autocorrelation) was rejected, thereby supporting the alternative hypothesis (*H1*: presence of first-order autocorrelation), indicating a significant existence of first-order autocorrelation. In contrast, for second-order autocorrelation (AR2), the null hypothesis (*H0*: no second-order autocorrelation) was not rejected, rendering the alternative hypothesis (*H1*: presence of second-order autocorrelation) invalid, suggesting that while the data did not provide evidence for second-order autocorrelation, the testing conditions remained valid. Furthermore, Hansen's test for overidentification yielded *p*-values greater than 0.1, confirming that the null hypothesis (*H0*: all overidentifying restrictions are valid) was not rejected, thus indicating that the alternative hypothesis (*H1*: at least one overidentifying restriction is invalid) does not hold.

Regarding whether past innovation strategies impact current innovation strategies, significant positive correlations exist between

Tab. 5: Main results

Variables	Panel A: innovative input strategies					
	R&D change			R&D growth		
	POLS *RDC* (1)	FEM *RDC* (2)	GMM *RDC* (3)	POLS *RDG* (4)	FEM *RDG* (5)	GMM *RDG* (6)
L.*RDC*	0.9358*** (0.0045)	0.5162*** (0.0158)	0.7418*** (0.0555)			
L.*RDG*				0.8956*** (0.0051)	0.5967*** (0.0138)	0.7429*** (0.0643)
DT	0.0003*** (0.0000)	0.0005*** (0.0001)	0.0013** (0.0006)	0.0620*** (0.0096)	0.0330 (0.0295)	0.3112** (0.1536)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	Yes	Yes	No	Yes	Yes
No. of firms	3,441	3,441	3,441	3,441	3,441	3,441
No. of IVs			28			24
AR (1)			0.0000			0.0000
AR (2)			0.3410			0.7140
Hansen J			0.4690			0.5320
R-squared	0.8790	0.8340		0.8620	0.8220	
N	22,910	22,910	22,910	22,910	22,910	22,910
Variables	Panel B: innovative output strategies					
	Substantive innovation			Strategic innovation		
	POLS *SUI* (7)	FEM *SUI* (8)	GMM *SUI* (9)	POLS *STI* (10)	FEM *STI* (11)	GMM *STI* (12)
L.*SUI*	0.8235*** (0.0048)	0.2891*** (0.0118)	0.3567*** (0.0278)			
L.*STI*				0.7927*** (0.0050)	0.2311*** (0.0110)	0.2731*** (0.0271)
DT	0.0324*** (0.0038)	0.0312*** (0.0094)	0.1646*** (0.0425)	0.0101** (0.0042)	0.0096 (0.0103)	0.0973** (0.0400)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	Yes	Yes	No	Yes	Yes
No. of firms	3,441	3,441	3,441	3,441	3,441	3,441
No. of IVs			27			35
AR (1)			0.0000			0.0000
AR (2)			0.1540			0.1180
Hansen J			0.3740			0.4920
R-squared	0.7320	0.5630		0.6980	0.4830	
N	22,910	22,910	22,910	22,910	22,910	22,910

Note: Statistical significance is indicated by *, **, and *** for the 10, 5, and 1% levels, respectively; robustness standard errors are provided in brackets.

Source: own

lagged innovation strategies (L.RDC, L.RDG, L.SUI, and L.STI) and current innovation strategies (RDC, RDG, SUI, and STI) in columns (3), (6), (9), and (12) of Tab. 5, confirming the dynamic nature of the four dimensions of innovation strategy. Columns (3), (6), (9), and (12) also report regression results testing the relationship between digital transformation (DT) and innovation strategies (RDC, RDG, SUI, and STI). The coefficients on DT are significant at the 1% levels (column (9)) and 5% (columns (1), (6), and (12)), indicating that DT has an overall significant and positive impact on corporate innovation strategies, whether in terms of innovative input strategies in R&D transformation intensity and R&D growth or output strategies in substantive innovation and strategic innovation. Therefore, it can be concluded that digital transformation drives corporate-level innovation strategies.

3.3 Robustness checks

In dynamic panel data models, using deeper lagged instrumental variables that have a lower correlation with the current error term can effectively reduce the endogeneity problem of the instruments, thereby improving the validity and consistency of the estimates (Jha, 2019). When implementing system GMM, a new dataset needs to be constructed from both the levels and differences. As lagged variables in levels are used to instrument the difference equation, lagged differences can again be utilized to construct a decomposed HENR-style instrument set, which provides an optimal weighted matrix of the moments of instruments and errors for each period after instrumenting the dependent variable (Roodman, 2009).

As an additional robustness check, we performed regressions using deeper lags as instruments in the system GMM estimation.

Tab. 6: Robustness checks of the dynamic panel

Variables	GMM *RDC* (1)	GMM *RDG* (2)	GMM *SUI* (3)	GMM *STI* (4)
L.*RDC*	0.7383*** (0.0464)			
L.*RDG*		0.7446*** (0.0641)		
L.*SUI*			0.3518*** (0.0281)	
L.*STI*				0.2717** (0.0271)
DT	0.0014*** (0.0005)	0.2755** (0.1269)	0.1623*** (0.0462)	0.0960** (0.0400)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
No. of Firms	3,441	3,441	3,441	3,441
No. of IVs	29	25	28	36
AR (1)	0.0000	0.0000	0.0000	0.0000
AR (2)	0.4890	0.6580	0.2260	0.1660
Hansen J	0.1110	0.6610	0.5160	0.5620
N	22,910	22,910	22,910	22,910

Note: Statistical significance is indicated by *, **, and *** for the 10, 5, and 1% levels, respectively; robustness standard errors are provided in brackets.

Source: own

Tab. 7: Robustness checks of the static panel

Variables	RE *RDC* (1)	RE *RDG* (2)	RE *SUI* (3)	RE *STI* (4)	RE *RDC* (5)	RE *RDG* (6)	RE *SUI* (7)	RE *STI* (8)
DT	0.0011*** (0.0001)	0.1481*** (0.0392)	0.0765*** (0.0092)	0.0301*** (0.0096)	0.0011*** (0.0001)	0.1284*** (0.0384)	0.0736*** (0.0092)	0.0266*** (0.0096)
MC	No	No	No	No	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
***R*-squared**	0.0590	0.1230	0.1680	0.1960	0.0750	0.1290	0.1660	0.1970
N	27,163	27,163	27,163	27,163	26,390	26,390	26,390	26,390

Note: Statistical significance is indicated by *, **, and *** for the 10, 5, and 1% levels, respectively; robustness standard errors are provided in brackets.

Source: own

The outcomes are detailed in Tab. 6. Specifically, the use of 2 lags (columns (1) and (2)) and 3 lags (columns (3) and (4)) for the DT indicator produced results consistent with those in Tab. 5 and successfully passed the weak Hansen instrument validity test. Overall, the system GMM estimates with deeper lags substantiate the positive effect of digital transformation on the four aspects of corporate innovation strategies.

In addition, we performed robustness checks using a static panel model with random effects (RE). By introducing RE, this model enables us to validate our results further across different scenarios while mitigating potential biases associated with fixed effects. As shown in columns (1–4) of Tab. 7, the positive coefficients of DT at the 1% significance level reinforce the consistency of our primary findings.

Furthermore, based on prior literature (e.g., Bello et al., 2021; Mikalef et al., 2019; Pu & Zulkafli, 2024; Reuschl et al., 2022), we recognize that certain managerial characteristics may impact both the adoption of DT and investment in innovation. Accordingly, we added three specific managerial control variables to the RE model: (1) managerial ownership: as a long-term incentive, managerial ownership aligns executives' interests with those of shareholders, which can promote investment in digital transformation initiatives and strengthen sustainable innovation strategies. This variable is measured by the percentage of shares held by management; (2) executive compensation: short-term compensation provides immediate incentives for managers, potentially encouraging them to pursue digital transformation initiatives with rapid innovation returns, thereby affecting the relationship between DT and innovation. We measure this by the annual total compensation of executives; (3) average managerial age: as an indicator of risk tolerance and openness to innovation, managerial age may influence the likelihood of adopting new technologies, including DT initiatives, and thereby impact the firm's overall innovation direction. This variable is measured by the average age of the management team.

Columns (5–8) in Tab. 7 present the results after controlling for these managerial characteristics (MC) variables. The results indicate that even after accounting for these factors, the findings remain robust and statistically significant with positive coefficients. These robustness tests confirm the positive and significant effect of digital transformation on the four dimensions of corporate innovation strategy (RDC, RDG, SUI, and STI) even within a static panel framework.

3.4 Discussion

Digital transformation heralds a fundamental shift in how enterprises operate, leveraging cutting-edge technologies such as artificial intelligence, blockchain, cloud computing, and big data analytics to significantly enhance their

capabilities in information processing and data analytics (Guo et al., 2022; Peng & Chang-Qi, 2022; Reuschl et al., 2022). This transformative process not only modernizes internal and external organizational structures but also revolutionizes operational processes and redefines models for value creation. Our study underscores the pivotal role of digital transformation in reshaping innovation strategies within firms, compelling increased investments in R&D to optimize future innovation outcomes. By harnessing digital platforms, organizations are better equipped to promptly identify and respond to emerging market opportunities and evolving consumer needs, thereby refining and optimizing their innovation strategies in a rapidly evolving competitive landscape.

Furthermore, our findings are consistent with existing research, emphasizing digital transformation as a critical driver of microeconomic impacts within enterprises. This transformative journey empowers firms with dynamic capabilities, as evidenced by its significant influence on strategic responsiveness and the enhancement of service and process innovations (Ferreira et al., 2019; Vial, 2019). Additionally, digital technologies play a pivotal role in mitigating information asymmetries between managerial decision-makers and shareholders, thereby reducing agency costs and fostering an environment conducive to increased R&D investments (Gong & Ribière, 2021; Rachinger et al., 2019). Moreover, these technologies streamline operational efficiencies, diminish knowledge gaps, and facilitate collaborative innovation efforts, thereby optimizing the efficiency and effectiveness of both innovation input and output strategies (Ma & Zhu, 2022; Şimşek et al., 2019; Srinivasan & Venkatraman, 2017). In conclusion, digital transformation not only redefines enterprise operations but also positions them strategically to thrive in an era defined by rapid technological advancement and evolving market dynamics.

Conclusions

Using data from Chinese A-share listed companies from 2012 to 2021, we investigated the impact of digital transformation on two key aspects of innovation strategies. On the one hand, digital transformation significantly promotes R&D investment strategies, both in terms of the intensity of R&D changes and the growth of R&D funding. On the other hand, a firm's digital transformation capabilities drive innovation output strategies, enhancing both strategic and substantive innovations. These findings hold up to tests involving lagged dependent variable within-group parameter tests and dynamic techniques using deeper lags of instruments.

This study offers crucial theoretical contributions and practical implications for scholars in the innovation field, national policymakers, and corporate leaders. From a theoretical perspective, it examines the influence of digital transformation on innovation strategies through the lenses of agency theory and resource dependence theory, affirming digital transformation as a significant factor in shaping innovation strategies. For innovation scholars, the use of deep learning modules and dynamic GMM estimation provides new methodological directions for exploring multi-dimensional digital transformation data. Furthermore, this research has substantial policy implications. It emphasizes that innovation strategies should be evaluated from both input and output perspectives concerning digital transformation. Given the vast scale of China's digital economy and the rapid growth of companies undergoing digital transformation, policymakers could strengthen digital technology infrastructure, enhance regulatory frameworks for digital technology protection, and provide subsidies to encourage firms to leverage digital transformation to accelerate substantive innovation elements. These insights are also valuable for other countries undergoing digital transformation, offering a blueprint for customizing digital pathways to enhance their innovation inputs and outputs. Lastly, recognizing the positive impact of digital transformation on innovation strategies, corporate decision-makers should embrace this trend, increase IT investments, and ensure they maximize the benefits of digital transformation in fostering innovation.

Nonetheless, this study has several limitations. First, it examines the impact of digital transformation on innovation strategies exclusively at the firm level, leaving opportunities for future research to investigate regional innovation spillovers. Second, the reliance on data from Chinese listed companies may constrain the generalizability of the findings to different economic, regulatory, and technological environments. Future studies could extend the analysis to include regional and

international contexts to provide a more nuanced understanding of the multifaceted effects of digital transformation on innovation.

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Determinants of logistics service supplier choice for electronics exporters: Evidence from an emerging market

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Abstract: *This study aims to explore important factors influencing the decision-making process in selecting logistics service suppliers by electronic component export companies in Vietnam, with a particular focus on local service providers (LSPs). The research involved in-depth interviews with eight logistics experts and a quantitative survey of 300 representatives from electronic component export companies. Data was collected through online surveys, then analyzed using the SEM model. The findings indicate that six key factors influence the decision-making process. Among them, cost competitiveness, the reputation of logistics suppliers, and service quality directly affect the selection of logistics services, while management capabilities, technical and information processing skills, and the pursuit of sustainable development have indirect effects. These results offer useful insights for LSPs, enabling them to align their services with the specific needs of electronic component exporters and improve their market competitiveness.*

Keywords: *Decision-making, supplier selection, logistics services, electronic components, logistics supplier, exporting enterprises, influencing factors, Vietnam market, organizational buying behavior, SEM model.*

JEL Classification: *F10, M110.*

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Introduction

In the global supply chain, logistics plays a necessary role in ensuring the efficient and timely movement of goods and services, especially for industries such as electronic components, where precision and efficiency are key to maintaining competitive advantage. As companies increasingly rely on specialized logistics service providers, understanding the factors that influence the selection of these providers becomes essential for both businesses and service suppliers.

In Vietnam, the electronic components industry has seen substantial growth, driven by foreign direct investment and increasing demand for energy-efficient devices. However, the success of this industry depends on the effectiveness of its logistics operations in certain aspects, particularly for companies involved in export activities. Logistics service providers

(LSP) are important partners in this process, as they offer tailored services to meet the complex needs of global supply chains (Binh & Linh, 2013).

This study focuses on the decision-making process of selecting logistics service providers by electronic component exporters in Vietnam. Specifically, we examine the key factors, such as cost competitiveness, service quality, and provider reputation, that influence this decision. Identifying these factors is crucial for both electronic component exporters and logistics providers to optimize their partnerships and improve overall supply chain performance (Martí & Puertas, 2015).

In this research, the term local service systems (LSS) refers to the network of logistics providers offering integrated services to businesses. While the term local service providers (LSP) is commonly used to refer to individual logistics companies, LSS is used to emphasize the systemic integration and collaboration between multiple service providers that contribute to a company's logistics strategy. This distinction is important for understanding the broader impact of logistics networks on the decision-making process.

The aim of this study is to analyze the key factors, such as cost competitiveness, service quality, and provider reputation that influence the decision-making process of selecting logistics service providers by electronic component exporters in Vietnam. By identifying these factors, the research provides valuable insights for logistics providers and exporting businesses to optimize their operations and improve overall supply chain performance.

1 Theoretical background

Building on the important role of logistics in supporting the electronic components industry, it is important to understand how organizational buying behavior theory informs the selection of logistics service providers (LSPs) in this context. The organizational buying behavior theory (Webster & Wind, 1972) highlights the complexity of purchasing decisions within organizations, focusing on factors such as risk mitigation, trust, and competitive actions that influence supplier selection. This theory provides a foundational framework for examining how electronic component exporters choose logistics service providers, particularly when balancing multiple considerations such as cost, service quality, and technological capability.

In recent years, the global electronic components industry has witnessed substantial growth, driven by advancements in technology and materials. Manufacturers have adopted innovations like low modulus elastic layers, metal members supporting semiconductor substrates, and composite materials with metal films to enhance performance and durability (Bajenescu & Bazu, 2012). The continuous push toward miniaturization and improved functionality has further accelerated this growth, making efficient logistics operations essential for maintaining competitiveness, especially for export-driven businesses. Logistics systems are necessary for optimizing inventory management, streamlining transportation, and managing reverse logistics processes (Yadav et al., 2019). As a result, selecting the right logistics provider becomes a key decision for businesses.

Research on logistics service provider selection has evolved beyond a narrow focus on cost to adopt a more holistic view that includes service quality and sustainability. Delcea and Cotfas (2023) argue that environmental sustainability has become increasingly important, with companies incorporating sustainability criteria into their supplier evaluation processes. Additionally, methodologies such as the analytic hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS) have been widely used to evaluate suppliers based on a range of criteria (Lin et al., 2023a). These methods enable organizations to weigh multiple factors in making informed and strategic decisions.

One of the relevant factors influencing supplier selection is reputation. The reputation of third-party logistics providers substantially affects their demand, with studies emphasizing the importance of reliability, efficiency, and trustworthiness (Sakas et al., 2023). Companies must carefully evaluate the reputation of logistics providers to ensure cost-effective operations, timely deliveries, and high customer satisfaction (Evdokimova & Kuchina, 2022).

In addition to reputation, cost competitiveness plays a notable role in logistics service provider selection. Pengman et al. (2022) note that global competition has driven logistics providers to focus on effective cost management and resource optimization. However, Hauser (2022) argues that superior logistics performance, not just cost reduction, enables companies to gain a competitive edge, highlighting

the importance of service excellence alongside cost control.

Technological capability is another considerable factor in selecting logistics providers. The integration of information technology (IT) systems into logistics operations has been shown to meaningfully improve service quality and efficiency. Akoğlu et al. (2022) highlight how the adoption of IT enables providers to meet customer demands more effectively, while Bazaras et al. (2023) emphasize the importance of continuous technological upgrades to maintain competitiveness in a rapidly changing market.

Sustainability is becoming an increasingly important factor in supplier selection. Leung et al. (2023) discuss how logistics providers are adopting green logistics initiatives, driven by both internal managerial attitudes and external market conditions. However, as Akhtar (2023) points out, while sustainability criteria are sometimes less prioritized compared to cost and service quality, there is a growing awareness of the need for a balanced approach that includes environmental and social considerations in supplier evaluation.

The organizational buying behavior theory provides valuable insights into these selection processes, as it highlights how factors such as cost reduction motivations, service supplier characteristics, and outsourcing strategies influence logistics decisions (Binh & Linh, 2013). In particular, the intelligent transformation of logistics services and power dynamics in the logistics supply chain notably affect profitability and decision-making strategies (Cao et al., 2023; Wang & Hu, 2022). By applying this theoretical lens, we can better understand how businesses weigh various factors when choosing logistics service providers.

In summary, the selection of logistics service providers is a multi-dimensional process influenced by a combination of factors, including cost, service quality, reputation, technological capability, and sustainability. This study builds upon the existing literature by examining the specific factors that influence the decision-making process of electronic component exporters in Vietnam. The following section will propose research hypotheses based on the theoretical foundations and key findings from the literature review, aiming to test the relationships between the identified factors and the decision-making process for selecting logistics service providers.

1.1 Research model and hypotheses

The research model is constructed based on theories of organizational buying behavior and studies on factors influencing logistics service supplier selection decisions for exporting companies (Fig. 1). The authors have chosen the following factors for study to measure their impact on the decision to select logistics service suppliers for electronic component export enterprises in Ho Chi Minh City: competition in service costs, the reputation of the logistics service supplier, service quality, technological capability and information processing, management capability of the logistics service supplier, and the ability to aim for sustainable development.

In addition to these six selected factors, several other factors were also considered, e.g., geographic proximity (Hesse & Rodrigue, 2004), flexibility in transportation (Naim et al., 2006), and innovation capability (Ho & Chang, 2015). However, after careful evaluation and consultation with experts through online meetings, these factors were excluded from the model as they do not play an important role in the specific context of electronic component exporting enterprises in Vietnam. For instance, while geographic proximity needs consideration in some industries, it becomes less effective in this study due to the involvement of large-scale logistics service providers, who are capable of operating efficiently on a national scale.

Decision to choose a logistics service supplier. The decision to select a logistics service supplier (LSS) is a critical aspect of supply chain management, influencing various facets of an organization's operations and performance. Studies highlight the importance of selecting suppliers based on quality, reliability, cost-effectiveness, and customer satisfaction. Modern decision-making models for LSS selection integrate industry-specific data analysis, multi-criteria decision-making methods, and hybrid models to enhance the selection process. Key criteria for evaluating LSSs include pricing, reliability, timeliness, flexibility, and service quality, with a focus on cost reduction, efficiency improvement, and customer relationship enhancement (Evdokimova & Kuchina, 2022). The digital environment provides tools for accessing large-scale databases for informed decision-making, optimizing the selection process based on customer requirements and operational needs (Nagy & Neff, 2024). Ultimately,

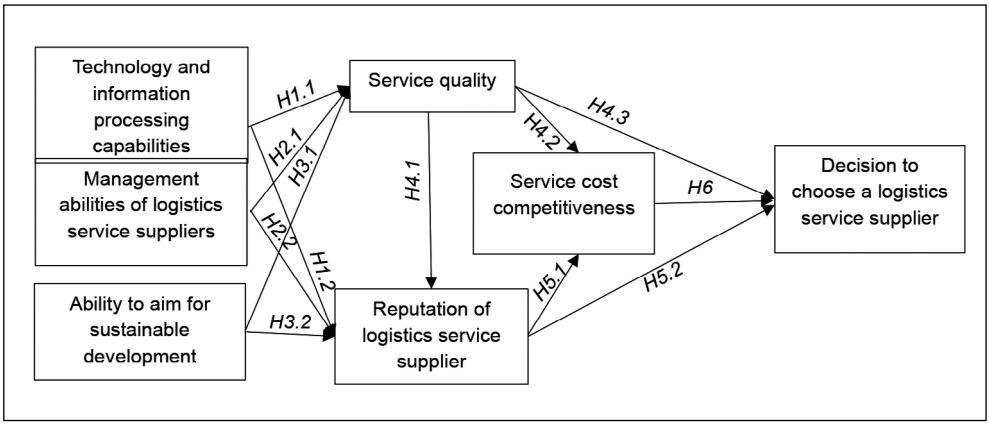

Fig. 1: Determinant factors of logistics service providers for electronic component import-export companies

Source: own

selecting the right logistics service supplier is important for achieving operational excellence, cost savings, and competitive advantage in today's dynamic business landscape.

Technology and information processing capabilities. Logistics service suppliers (LSSs) increasingly rely on technology to enhance their operations and meet the evolving demands of their customers. Cloud services, such as Amazon Web Services, Microsoft Azure, Google Cloud, Oracle Cloud, and SAP Cloud Platform, offer a range of tools for data storage, processing, and analysis, enabling efficient electronic data interchange (EDI) systems (Alnaimat et al., 2024). Additionally, the development of technological infrastructure and IT systems facilitates secure information storage and exchange, streamlining order processing and service efficiency (Bazaras et al., 2023). The utilization of information technology (IT) by LSSs significantly impacts their performance and competitiveness, as IT capabilities complement service processes and drive innovation, ultimately affecting the company's competitive advantage (Nour, 2022). By having these technological advancements, logistics service suppliers can improve their operations, thereby enhancing service quality and reputation.

H1.1: The technology and information processing capabilities of logistics service suppliers affect the quality of their services.

H1.2: The technological and information processing capabilities of logistics service suppliers affect their reputation.

Management abilities of logistics service suppliers. Logistics service suppliers (LSSs) play a pivotal role in supply chain management by delivering flexible and adaptive services without compromising on quality or incurring additional costs (Nagy & Neff, 2024). Effective management of customer partnerships is crucial for fostering long-term relationships and improving overall service quality and performance. Additionally, LSSs' ability to efficiently resolve disputes among stakeholders contributes to smoother operations and the maintenance of positive relationships throughout the supply chain, ultimately enhancing organizational performance and reputation (Zadajali & Ullah, 2024). Therefore, the management capabilities of logistics service suppliers significantly contribute to their quality and reputation.

H2.1: Management abilities of logistics service suppliers affect the quality of their services.

H2.2: Management abilities of logistics service suppliers affect their reputation.

Ability to aim for sustainable development of logistics service suppliers. By focusing on sustainable practices, such as those outlined in the study of Su et al. (2022), suppliers from developing countries can achieve a competitive advantage and promote sustainable transformation in multinational supply chains. Understanding the key attributes of sustainable logistics is essential for evaluating logistics activities and selecting partners who prioritize

sustainability, thereby aligning with the broader concept of sustainable development (Mohsen, 2023). Additionally, research of Dovbischuk (2021) underscores the importance of the internal capabilities of LSSs in achieving sustainability-oriented corporate performance, demonstrating the significance of organizational readiness and capacity in advancing sustainable logistics practices (Dovbischuk, 2021). Thus, the sustainability orientation of logistics service suppliers significantly influences their service quality and reputation.

H3.1: Ability to aim for sustainable development of logistics service suppliers affects the quality of their services.

H3.2: Ability to aim for sustainable development of logistics service suppliers affects their reputation.

Service quality of logistics supplier. Research highlights the importance of service quality in logistics, emphasizing aspects such as timeliness, availability, condition, operational quality, resource quality, information quality, personal contact quality, and customization quality (Lin et al., 2023b). Evaluating logistics service suppliers based on indicators such as prompt response to customer requests, minimal errors, service diversity, staff expertise, and adequate facilities is essential to meet customer demands and maintain competitive advantage (Yuliawati et al., 2023). By focusing on these aspects, logistics companies can enhance customer satisfaction, improve service quality, and promote sustainable success in the industry. The aforementioned factors influence service quality's impact on the reputation, competitive pricing of logistics services, and the decision-making process of export companies when selecting service suppliers.

H4.1: The service quality of logistics service suppliers affects their reputation.

H4.2: The service quality of logistics service suppliers affects their service cost competitiveness.

H4.3: The service quality of logistics service suppliers affects the choice decisions of their customers.

Reputation of logistics service supplier. The reputation of logistics service suppliers is a significant factor influenced by various aspects such as enterprise scale, network partnerships with customers and major carriers, extensive industry achievements, past performance, and trust from companies within the sector. Studies underscore the importance of factors such as accuracy, reputation, IT capabilities, reliability, service efficiency, and dependability in maintaining collaboration with 3PL suppliers (Sakas et al., 2023). Additionally, the quality of logistics services is assessed based on criteria like company reputation, product availability/quality, reliability/flexibility, and consumer services, with a particular emphasis on customer perceptions of service quality (Kolodizieva et al., 2022). The collaborative network in logistics also highlights the importance of managing reputational risk to encourage participation and strengthen relationships among suppliers, logistics service suppliers, and end customers (Anes et al., 2022). These findings highlight the multifaceted nature of logistics service suppliers' reputation and the diverse factors contributing to building and maintaining a positive image in the industry. Consequently, the reputation of logistics service suppliers impacts competitive pricing and the decision-making process of electronics component export companies when selecting service suppliers.

H5.1: The reputation of logistics service suppliers affects the cost competitiveness of their logistics services.

H5.2: The reputation of the logistics service supplier affects the decision to choose a logistics service supplier for companies exporting electronic components.

Service cost competitiveness. When choosing a logistics service supplier for effective supply chain management, cost competitiveness is an important consideration. Low freight and main route fees, avoiding excessive local fees, providing a variety of services at competitive prices, and having straightforward, efficient, and economical payment policies are all important, according to research (Afum et al., 2021). According to research, in order to improve cost competitiveness and satisfy consumers' growing needs, logistics service providers should make investments in logistics services, use best practices, and work with clients (Zadajali & Ullah, 2024). Additionally, studies conducted on Southeast Asia show that, because of government-related factors, Vietnam is the most desirable location for logistics services, while Thailand is a desirable option for low-cost logistics solutions due to its cost

competitiveness (Tran & Pham, 2021). These results emphasize how important cost competitiveness and efficient cost control techniques are when choosing logistics service suppliers.

H6: Supplier service cost competitiveness affects the decision to choose a logistics service supplier of electronic components exporters.

After developing the research hypotheses based on the factors influencing the decision to select logistics service providers, the next section will present the research methodology used to test these hypotheses. This section will provide a detailed description of the data collection process, the survey sample, and the statistical analysis methods employed to ensure the accuracy and scientific rigor of the study's conclusions.

2 Methodology

The study employed a structural equation modeling (SEM) approach to analyze the relationships between various factors influencing the decision to choose logistics service suppliers among electronics exporters in Vietnam. SEM was selected because it allows for the examination of complex relationships between observed and latent variables and can evaluate both direct and indirect effects within the model. This method is particularly useful when dealing with multi-dimensional constructs, as it provides robust insights into the causal relationships among multiple variables (Hair et al., 2010).

Before applying SEM, descriptive statistics were conducted to summarize the demographic characteristics of the sample. Normality tests were also carried out to ensure that the data met the necessary assumptions for SEM analysis. In addition, the Kaiser-Meyer-Olkin (KMO) test was employed to measure the adequacy of the sample selection, and Bartlett's test of sphericity was used to determine whether the variables were uncorrelated in the population, ensuring the suitability of the data for factor analysis.

Data was collected using a combination of deep interviews with experts, and online surveys. Interviews involved online meetings with 8 logistics experts and representatives from exporting companies via Google Meet application, where the authors consulted their opinions and suggestions for the questionnaire design. Then, the questionnaire form was finalized with six key factors influencing the decision-making process before its Google Form link was sent to the respondents. This method allowed for deeper insights into the decision-making criteria while ensuring a high response rate and data accuracy. In this study, experts are defined as individuals with more than 5 years of experience at management level in the logistics field, or lecturers in related disciplines who have over 5 years of teaching experience and have published papers in this area. The survey participants are employees working in various positions at electronic component exporting companies. Data collection took place between May and July 2024, with a total of 300 responses collected. After data cleaning, 230 valid responses were retained for analysis.

Once the data was collected, they were processed using SPSS for initial descriptive analysis and validity tests. Exploratory factor analysis (EFA) was conducted to identify the underlying structure of the data, and this was followed by confirmatory factor analysis (CFA) to confirm the factor structure before integrating the data into the SEM model. The SEM analysis was carried out using Stata 16 software, which allowed for the estimation of both the measurement and structural components of the model.

The analysis was conducted in two stages: first, a measurement model was estimated to assess the reliability and validity of the constructs. Cronbach's alpha was used to ensure internal consistency. Next, the structural model was tested to evaluate the relationships between the independent and dependent variables, including the direct and indirect effects of factors such as cost competitiveness, service quality, and provider reputation on the decision to choose logistics service suppliers.

Overall, the use of SEM in this study provided a comprehensive approach to analyzing complex relationships between multiple variables, while the integration of other statistical methods, such as KMO and Bartlett's tests, ensured the robustness and validity of the results.

With the research methodology established, the collected data underwent a thorough analysis to test the research hypotheses. The following section will present the key results from this analysis, illustrating the relationships between the identified factors and the decision-making process of selecting logistics service providers by businesses.

3 Results

3.1 Reliability statistics

The reliability analysis shows that all the constructs in the model have a reliability higher than 0.7. According to Hair (2010), the scale must ensure one-dimensionality and reliability, achieving a Cronbach's alpha threshold of 0.7 or above. Therefore, all seven constructs of the model, including technology and information processing capability (0.749), service management ability of the logistics service supplier (0.888), ability to aim for sustainable development of logistics service suppliers (0.778), service quality (0.840), reputation of the logistics service supplier (0.809), cost competitiveness of services (0.818), and decision to choose a logistics service supplier (0.815), are all unidimensional and reliable.

The KMO and Bartlett's test findings indicate that the data is appropriate for exploratory factor analysis, or EFA. The results of Bartlett's test show a tiny *p*-value (Sig. = 0.000 < 0.05) and a high KMO value (0.854 > 0.8), indicating that the variables are correlated, and the data is structured (Tab. 1).

Tab. 1: KMO and Bartlett's test

Measure		Value
Kaiser-Meyer-Olkin measure of sampling adequacy		0.854
Bartlett's test of sphericity	Approx. chi-square	2,461.320
	df	276.000
	Sig.	0.000

Source: own

Tab. 2: Total variance explained – Part 1

Factor	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings*
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total
1	7.044	29.351	29.351	6.618	27.573	27.573	4.854
2	2.320	9.667	39.018	1.884	7.848	35.421	4.366
3	2.173	9.054	48.073	1.733	7.223	42.644	3.867
4	1.875	7.814	55.886	1.433	5.973	48.617	3.423
5	1.511	6.297	62.184	1.069	4.452	53.069	2.126
6	1.155	4.812	66.996	0.736	3.065	56.134	4.005
7	0.740	3.085	70.081				
8	0.684	2.850	72.931				
9	0.659	2.745	75.676				
10	0.602	2.509	78.185				
11	0.556	2.316	80.501				
12	0.510	2.127	82.628				
13	0.484	2.017	84.645				
14	0.461	1.922	86.566				
15	0.443	1.844	88.411				

Tab. 2: Total variance explained – Part 2

Factor	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings*
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total
16	0.409	1.706	90.117				
17	0.394	1.641	91.758				
18	0.380	1.583	93.340				
19	0.329	1.370	94.710				
20	0.293	1.221	95.931				
21	0.276	1.148	97.080				
22	0.268	1.117	98.197				
23	0.236	0.982	99.178				
24	0.197	0.822	100.000				

Note: * when factors are correlated, sums of squared loadings cannot be added to obtain a total variance; extraction method: principal axis factoring.

Source: own

Tab. 3: Pattern matrix* – Part 1

	Factor					
	1	2	3	4	5	6
SMA3	0.850					
SMA1	0.800					
SMA5	0.751					
SMA4	0.740					
SMA2	0.729					
QUAL2		0.837				
QUAL3		0.785				
QUAL1		0.695				
QUAL4		0.635				
QUAL5		0.566				
COST3			0.774			
COST4			0.727			
COST1			0.725			
COST2			0.671			
REP4				0.793		
REP2				0.698		
REP3				0.664		
REP1				0.657		

Tab. 3: Pattern matrix* – Part 2

	Factor					
	1	2	3	4	5	6
TIP2					0.817	
TIP1					0.651	
TIP3					0.650	
SDA3						0.739
SDA2						0.736
SDA1						0.671

Note: * rotation converged in 6 iterations; extraction method: principal axis factoring; rotation method: promax with Kaiser normalization.

Source: own

From Tabs. 2–3, it can be observed that six factors have been identified to explain the factors influencing the decision to choose logistics service suppliers for electronics component export businesses in Ho Chi Minh City. These six factors include: technology and information processing capability (TIP1: the logistics service provider has a convenient and efficient electronic data interchange (EDI) system; TIP2: the provider has a simple, user-friendly, and efficient order processing system and other related services; TIP3: the logistics service provider can securely store and safeguard the information provided by your company), service management ability of the supplier (SMA1: the logistics service provider is able to quickly adapt to sudden changes; SMA2: the logistics service provider demonstrates strong financial stability; SMA3: the logistics service provider maintains a high service completion rate; SMA4: the logistics service provider is proficient in managing customer partnerships; SMA5: the logistics service provider is capable of effectively and promptly resolving disputes between parties), ability to aim for sustainable development (SDA1: the logistics service provider demonstrates a high level of economic responsibility; SDA2: the logistics service provider exhibits a strong commitment to social responsibility; SDA3: the logistics service provider shows a high degree of environmental responsibility), service quality (QUAL1: the logistics service provider responds promptly and timely to customer requests; QUAL2: the logistics service provider exhibits minimal operational errors; QUAL3: the logistics service provider offers a diverse range of services; QUAL4: the logistics service provider has sufficient facilities to meet the needs of the business; QUAL5: the logistics service provider has adequate facilities, such as warehouses and domestic transportation vehicles, to meet the company's needs), reputation of the logistics service supplier (REP1: the logistics service provider has an extensive partner network; REP2: the logistics service provider has a strong track record in the industry; REP3: the logistics service provider has demonstrated strong operational capabilities in the past; REP4: the logistics service provider collaborates with numerous companies), and cost competitiveness of services (COST1: the logistics service provider offers competitive freight rates; COST2: the logistics service provider incurs minimal costs prior to the main transportation phase; COST3: the logistics service provider offers a variety of service and cost incentives; COST4: the logistics service provider implements simple, efficient, and cost-effective payment policies and methods).

3.2 The suitability of the proposed model

The model fit analysis findings show that the suggested model does a good job of fitting the data. This model fits the data quite well, as seen by the RMSEA index (Xie & Yang, 2023), which falls within a good range with a 90% confidence interval from 0.041 to 0.058. There is about a 48.9% likelihood that the model fits extremely well, according to the 0.489 probability

of the RMSEA being less than or equal to 0.05. The low values of AIC (12,024.786) and BIC (12,361.291) suggest that the model is plausible and not excessively complicated. Both the TLI (0.929) and CFI (0.938) indices are above 0.90, indicating that the model fits the data set better than the baseline model. There is just a slight variation between the expected and observed values, as indicated by the SRMR (0.068), which is likewise within a reasonable range. Lastly, the almost perfect CD index (0.993) indicates that the model does a very good job of explaining the variability of the data. Other indices, such RMSEA, CFI, and SRMR, imply that this model is dependable and helpful even if the chi-square index has a relatively tiny *p*-value, indicating that the model does not match the data exactly. All things considered, this model works well and may be utilized for more research.

Factors affecting the quality of logistics services. From the SEM model results (Tab. 4),

Tab. 4: The results of SEM model

Structural effect	Observed information matrix					
	Coefficient	Standard error	*z*	*P* > *z*	Confidence interval (95%)	
Service quality (QUAL)						
TIP	0.132	0.078	1.700	0.089	−0.020	0.284
SMA	0.296	0.065	4.560	0.000	0.169	0.424
SDA	0.290	0.088	3.310	0.001	0.118	0.463
Reputation of logistics service supplier (REP)						
QUAL	0.281	0.102	2.750	0.006	0.081	0.482
TIP	−0.042	0.086	−0.490	0.623	−0.210	0.126
SMA	0.079	0.073	1.070	0.283	−0.065	0.223
SDA	0.215	0.097	2.220	0.026	0.026	0.405
Service cost competitiveness (COST)						
QUAL	−0.220	0.082	−2.690	0.007	−0.381	−0.060
REP	−0.361	0.086	−4.190	0.000	−0.529	−0.192
Decision to choose a logistics service supplier (DEC)						
QUAL	0.671	0.094	7.120	0.000	0.486	0.856
REP	0.264	0.085	3.120	0.002	0.098	0.430
COST	−0.361	0.089	−4.040	0.000	−0.537	−0.186

Source: own

it is evident that all three factors – information and technology capability (coef. = 0.132), service management ability of the supplier (coef. = 0.296), and orientation towards sustainable development (coef. = 0.290), have a positive impact on service quality. Among these, the service management ability of the supplier has a stronger influence than the ability to aim for sustainable development at a 5% significance level, while information and technology capability has a lower impact compared to the other two factors at a 10% significance level. These results support hypotheses *H1.1*, *H2.1*, and *H3.1*.

Factors influencing the reputation of the logistics service supplier. Among the four factors proposed by the model, service quality (coef. = 0.281) and ability to aim for sustainable development (coef. = 0.215) have a positive and statistically significant impact on the reputation

of the logistics service supplier at a 95% confidence level. However, the factors of technology and information processing capability, and service management ability of the supplier do not have a significant impact on the supplier's reputation. Therefore, hypotheses *H4.1* and *H3.2* are supported, while hypotheses *H1.2* and *H2.2* are not.

Factors influencing logistics service cost competitiveness. The cost competitiveness of logistics services is determined by service quality (coef. = −0.220) and the reputation of the service supplier (coef. = −0.361) at a 5% significant level. This means that when logistics service suppliers offer higher quality services or have a better reputation, their service costs are less competitive. Moreover, companies known for high-quality services and good reputations often charge higher transportation fees and incur local charges to enhance service quality, providing fewer cost incentives. These results support hypotheses *H4.2* and *H5.1* but in a negative direction.

Factors influencing the decision to choose a logistics service supplier. Three factors proposed by the model significantly impact logistics services: the service quality of the supplier (coef. = 0.671), the reputation of the supplier (coef. = 0.264), and the cost competitiveness of logistics services (coef. = −0.361). All three factors have a significant impact on the dependent variable; notably, service quality has the strongest effect. This indicates that Vietnamese electronics component export companies prioritize service quality the most. Next is the supplier's reputation, showing that Vietnamese exporters tend to choose suppliers with good reputations. However, there is a paradox where the reduction in cost competitiveness of logistics services seems to negatively affect the decision to choose logistics service suppliers for Vietnamese electronics component export companies. This indicates a willingness to trade off price for service quality and peace of mind when selecting logistics service suppliers among these companies.

In summary, service quality, supplier reputation, and cost competitiveness are the three factors directly influencing the decision to choose logistics service suppliers for Vietnamese electronics component export companies. While service quality and reputation have a positive impact, cost competitiveness negatively influences the decision. Additionally, other factors such as technology and information processing capabilities, the service management ability of the logistics supplier, and their orientation towards sustainable development indirectly affect the decision by impacting logistics service quality and enhancing the supplier's reputation. This result aligns with Webster and Wind's (1972) organizational buying theory regarding technology and information processing, logistics service management ability, ability to aim for sustainable development, service quality, and the reputation of logistics service suppliers. However, an interesting divergence in this study is that cost competitiveness, contrary to some previous studies, negatively affects the decision to choose logistics service suppliers (Huang et al., 2020; Webster & Wind, 1972; Zadajali & Ullah, 2024) but corresponding with the research of Tran and Pham (2021) stating that Vietnam is the most desirable location for logistics services. This can be explained by the fact that most major electronics component export companies in Vietnam are multinational corporations such as Sony, Samsung, and LG. These companies tend to select logistics service suppliers with better quality rather than prioritizing those with good cost competitiveness. However, most high-quality logistics service suppliers in Vietnam tend to have less cost competitiveness because they invest heavily in their service quality. Therefore, electronics component export companies in Vietnam often choose logistics service suppliers with less competitive costs.

Based on the results analyzed in the previous section, the discussion and conclusion will summarize the key findings of the study. Additionally, this section will provide practical recommendations for logistics service providers and suggest directions for future research to further explore the factors influencing the decision to select service providers.

4 Discussion

The SEM regression results show that three main factors affecting the logistics service quality are: technology and information processing capabilities, management abilities of logistics service suppliers, and ability to aim for sustainable development. These three aforementioned factors have a positive impact on service quality. In which, management abilities of logistics service suppliers have the strongest effect, followed by ability to aim for sustainable

development, and last but not least, is technology and information processing capabilities.

Compared to previous research, this result is similar to the findings of Ho and Chang (2015), indicating that factors relevant to integration and transportation safety, as well as the reliability and the responsiveness of the service, significantly affect the decision of choosing logistics service supplier. However, our research goes deeper into the relationship between logistics service quality and abilities to aim to sustainable development, which is briefly mentioned by the research of Ho and Chang (2015).

With regard to factors affecting the reputation of logistics service providers, the results show that service quality and ability to aim for sustainable development are the two main factors. This result supports the hypotheses *H4.1* and *H3.2*, which is in line with the results of Akhtar (2023), which emphasize the importance of sustainable development capabilities, especially the practice of environment protection and service reliability. On the other hand, technology and the capabilities to process information have a positive impact on quality service, though bear no significance to the service provider population. This is different from the conclusion of Yuliawati et al. (2023), which assumes that the availability and condition of products strongly affect the reputation, as well as the performance of service suppliers.

Regarding the variables influencing the competitiveness of logistics service costs, the findings indicate that the quality of service and the reputation of the service provider have the most negative effects on cost competitiveness. This demonstrates that service providers with higher ratings or better services typically offer higher-quality services, which makes them more cost-competitive. This finding runs counter to research of Afum et al. (2021), which shows that logistics outsourcing boosts cost competitiveness. This result contrasts with the research of Afum et al. (2024), which indicates that logistics outsourcing has positive effect to cost competitiveness. The different research contexts and different business subjects may explain this. In the case of Vietnam, electric component exporters tend to prioritize service quality rather than cost, which is consistent with the organizational purchasing theory by Webster and Wind (1972).

Finally, when taking into consideration factors affecting the decision to choose the logistics service provider, service quality is the factor having the strongest effect, followed by the reputation of the service provider, and the competitiveness of logistics service cost. This shows that electric component exporters in Vietnam particularly pay attention to service quality and provider's reputation. This is similar to the conclusions made by Yuliawati et al. (2023), which emphasize the importance of delivery speed, reliability, and product storage conditions in the decision of service providers. However, there is a paradox that the cost competitiveness has a negative impact on this decision, which is contrary to the previous results, especially research by Afum et al. (2024) when they discover that cost has a positive impact on the decision to choose service suppliers.

These results provide an insight into the decision of logistics service providers in Vietnam, especially in the context of electronic component exporter. It not only consolidates the previous theories regarding the role of service quality and reputation, but also opens new discussions about the relationship between cost service and decision to choose a suitable supplier, especially in the context that service quality and reliability is higher evaluated than cost.

Conclusions

The research identified six factors having impact on the decision to select the logistics services provider, including cost competitiveness, reputation, service quality, management abilities, information technology process capabilities, and ability to aim for sustainable development. In which, service quality, service provider reputation, and cost competitiveness have the direct effect on the service using decision of electronic component exporters.

Particularly, the research results indicated that businesses tend to highly evaluate the service quality and reputation rather than cost, and this reflects the fact that businesses are willing to pay extra costs to ensure high-quality and reliable services. This shows that logistics service suppliers in Vietnam need to enhance their service and develop their reputation if they wish to attract electronic component exporters. At the same time, investment in technology and information processing capabilities, improvement of management abilities, and focus on sustainable development also play important roles in increasing the service quality and reputation of suppliers.

This conclusion should provide an insightful look at the behavior of choosing logistics service providers of electronic component exporters in Vietnam, at the same time contributing to the launch of strategies that help to improve logistics service to attract business customers.

Although this study has provided valuable insights into the factors influencing the selection of logistics service providers by electronic component export businesses in Vietnam, several limitations remain. First, the survey sample primarily focuses on businesses in the Ho Chi Minh City area, which may not fully capture trends and influencing factors in other regions. Second, the study only examines factors within a specific period, while influencing factors may evolve over time due to market fluctuations and advancements in logistics technology. Lastly, the use of SEM analysis may not entirely capture non-quantitative factors such as cultural aspects and personal relationships in the decision-making process. These limitations suggest directions for future research to expand the scope and improve the accuracy of the conclusions.

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The link between corporate strategy and innovation in developing countries: The post-crisis trends and challenges

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Abstract: *This study aims to identify interrelationships between corporate strategy and innovation in developing countries in the post-COVID-19 context. The purpose of the study is to form a model that would allow to consider and process the impact of the innovational operations to the choice of the corporate strategy and its development within the operational domains of the developing countries, which ultimately can be able to meet the challenges in their economic growth and therefore contribute to the better outcomes of the post-crisis situations. The research hypotheses are that the post-crisis innovation activities do not depend on (H1) the ownership of the firm, (H2) its scale of operation, (H3) and industry but on (H4) the firm's life cycle stage, and (H5) the strategy complexity level. Here, the survey of 424 random respondents from 424 Chinese firms provides evidence that refutes the first and third hypotheses (H1 and H3) while confirming other hypotheses (H2, H4 and H5). In addition, most respondents disagreed with the statement that "innovation is of secondary importance during the post-crisis period," which suggests that innovation is a prerequisite for sustainable development. In addition to the previous research connected with the issues of corporate strategy and innovation, the present study has come up with the original hypotheses providing refutations and a new vision to the problem. The research findings present an extension to the understanding of corporate strategy and innovation during the post-crisis period, hence leading to the emergence of the up-to-date instruments able to solve the issues of the real economy after the COVID-19 crisis. The questionnaire, chosen as the research method, consisted of 18 2-section items, including a 7-item respondent profile and a 9-item analytical section. The respondent profile's questions were: year of establishment of the firm (Q1), form of ownership (Q2), respondent's position at the enterprise (Q3), sector in which the firm operates (Q4), firm size (Q5), profitability dynamics (Q6) and employment dynamics (Q7). The analytical section asked about the corporate strategies and innovation interactions. Q11 and Q12 resulted in 19.3% and 23.2% higher positive choice by private and limited liability firms, agricultural firms' results were 27.3% below the average, start-ups and new firms' activities demonstrated 14.7% more intensive innovative steps. Diversification is linked to the increased involvement into innovations, while the decreased level of innovation activity is linked to merger and acquisition practices. Ultimately, the first and second hypotheses (H1 and H3) were empirically proved to be false, and the remaining hypotheses (H2, H4 and H5) were confirmed. The present findings can be used to inform corporate strategy decisions in the real sector of the economy after the COVID-19 pandemic.*

Keywords: *Corporate strategy, innovation, link between corporate strategy and innovation, post-crisis economy, sustainable development.*

JEL Classification: *H12, M14, Q56.*

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Introduction

The beginning of the 21st century was marked by a large number of challenges, often transcending national boundaries and requiring supranational solutions. Amidst the rapid advancement in technology, which redefined nearly every sphere of human activity, the strategic management requirements of a firm have shifted to a fundamentally new plane. The devastating consequences of climate change, natural disasters, and large-scale epidemics implicating the turbulence of the global economy also played a part in this transition. Therefore, researchers have continued to create various corporate strategies over the past decades (Feldman, 2020; Mendes, 2018). As an eminent driver of corporate development (Christensen et al., 2018), innovation has attracted the attention of both academia and companies in the real sector of the economy (Dong et al., 2024; Dzhuzha et al., 2020; Karpuntsov & Veresha, 2022; Menz et al., 2021). The COVID-19 pandemic, on the other hand, has radically changed the business environment once again, exposing the many shortcomings of the management system. The efficient and streamlined business models, considered virtually flawless before the pandemic, have proven to have fragile supply chains, and transnational businesses that relied heavily on the international division of labour turned out to be vulnerable (Ozdemir et al., 2022). In these conditions, corporations sought to shift focus from flexibility, frugality, environmental friendliness, and efficiency to sustainability, reliability, and risk management (Ozdemir et al., 2022). This decision seems logical, yet when developing a corporate strategy, changing the priorities may affect the innovation aspect of the strategy. The risk of this happening necessitates empirical research into the mutual influence of post-crisis corporate strategy on innovation. Of particular importance is exploring the said link in the context of transition economies, as they ended up having much greater vulnerability to global shocks and because little is known about the relationship between innovation and corporate strategy in developing countries. Hence, the present study aims to identify interrelationships between corporate strategy and innovation in developing countries.

1 Theoretical background

Corporate strategies and innovations play a prominent role in ensuring that companies stay competitive in the face of external challenges; thus, it is no surprise that many researchers express interest in establishing how these two components interrelate (Farida & Setiawan, 2022; Issa & Bensalem, 2023; Waldron et al., 2022). Despite a significant number of publications, the existing literature is fragmented.

A survey-based study of more than 400 manufacturing companies in China suggests that corporate social responsibility (CSR) practices have the power to promote green product innovation and green process innovation (Yuan & Cao, 2022), with green dynamic capability as a mediator. Even though the study point is of practical importance and offers guidance to improve green innovation in the manufacturing sector, it delivers a "green" perspective exclusively, leaving a substantial portion of possible relationships outside the boundaries of research (Yuan & Cao, 2022).

Another study examined the role of business model innovation (BMI) in enhancing companies' performance in export markets (Najafi-Tavani et al., 2025). The novelty- and efficiency-centred innovations were reported to boot performance by strengthening exporter differentiation and cost advantages. Their effectiveness, however, can vary depending on relational embeddedness, international experience, and competitive intensity. The novelty-centred BMI is more likely to lead to a differentiation advantage if companies operate in moderately competitive environments but only in a narrow set of countries (Najafi-Tavani et al., 2025). Internationally active exporters that build strong connections with their customers can, in turn, attain cost advantages from efficiency-oriented BMI (Najafi-Tavani et al., 2025). Despite the undeniable relevance of these findings, researchers have narrowed the focus to a single innovation type (business

model innovation) and a specific category of business actors (exporting firms).

There is empirical evidence that manufacturing companies invest more in innovation activities amid digital transformation (Wen et al., 2022). The scale of operation, ownership, and productivity are not the influence factors in this process. At the same time, high-viability firms were reported to experience more prominent innovation incentive effects (Wen et al., 2022). Digitalization was said to have an indirect impact on the market competition strategy. For instance, it can encourage companies to implement differentiated competitive strategies while hindering the adoption of a cost-competitive practice (Wen et al., 2022).

It is obvious that the way to improve the process of manufacturing in any country, including China, depends a lot on the modern trends of digitalisation. It is the basis for the construct that speeds up the manufacturing value chains for China inside the country and on the global scale, as well. In this connection, a number of modifications in the manufacturing industry of China are currently taking place (Zhang, 2024).

Among studies that have explored innovation-centered strategies, Wang et al. (2020) investigated the response of Chinese firms to COVID-19 with respect to external influences, internal advantages, and characteristics of firms. The typology proposed by the researchers distinguishes the primary types of innovations based on motivation and the level of collaborative innovations. Heinonen and Strandvik (2020) classified the so-called "imposed" innovations by strategic horizon and strategic stretch. The classification system they offered covers 11 domains: social initiative, delivery, physical distancing, remote presence, entertainment, health and well-being, professional consultation, social connection, education, COVID-19 experience, and public innovations (Heinonen & Strandvik, 2020). For Caballero-Morales (2021), innovation appears as a recovery strategy for small and medium-sized businesses that operate in developing countries amid the COVID-19 pandemic. In this context, the adoption thereof can help companies create new products for new markets and implement the limited resources with greater efficiency.

The developing countries are gradually getting to the responsible behaviour in structural renovations with the use of modern technologies, in order to follow digitalisation and de-carbonisation of their industrial operations at a much larger level. Yet, the extent to which it has been completed so far is not good enough for the time being, hence it demands following more safeguard strategic measures to improve their industrial policy and find the balance between the national interest in regional and international collaboration, showing the commitment to the global trends (Santiago et al., 2024).

Leadership also plays a rather important part in managing enterprises of all sizes. Nowadays, the performance of the business can be influenced by the changes that are implemented by the management, and thus top decisions can be handled more efficiently and influence the resilience of the enterprise. There exist rather strong connections between leadership strategies and social capital, as well as business performance in many different regions. The most important thing is to figure out the particular circumstances in which social capital is to be used for better business performance and efficiency that can be applied to both financial and technological contributions (Reniati et al., 2024).

The theoretical literature review thus shows that despite the evident increase in interest toward the mutual influence of innovation on corporate strategy among researchers (Bahoo et al., 2023; Li et al., 2023; Waldron et al., 2022), there is no consensus regarding this relationship, nor there is a unified methodological approach to explore it. While acknowledging the contributions of predecessors (Sahoo et al., 2023; Verbeke & Yuan, 2021), one should note that the current research is either descriptive or theoretical (Mendes, 2018) and that some studies address a narrow aspect of the problem (Bier & White, 2021; Le, 2022; Phung et al., 2023). It makes it much more difficult to adapt research findings for other industries or economic conditions. Thus, the previously conducted studies for the time being have not been touching upon the matter of a set of recommendations for the use of innovations as a driving force of corporate culture development in the emerging economies, especially in the post-Covid crisis circumstances. Hence, the new hypothesis are urgent to be proposed as a way out not only in understanding the current trends, but also in working out a particular feasibility study in a more expanded scale to be applied to the particular needs of the corporate sector

in the Eastern economies, with the necessary specifications that, in the long run, are to be designed in order to facilitate the interaction between the stakeholders and corporations.

1.1 Problem statement

Based on the theoretical sources reviewed, the hypotheses were formulated (Farida & Setiawan, 2022; Wen et al., 2022). Overall, there are five research hypotheses to refute and confirm within the frames of the present research:

H1: The post-crisis innovation activities do not depend on the ownership of the firm.

H2: The post-crisis innovation activities do not depend on its scale of operation.

H3: The post-crisis innovation activities do not depend on industry.

H4: The post-crisis innovation activities depend on the firm's life cycle stage.

H5: The post-crisis innovation activities depend on the strategy complexity level.

This study aims to identify interrelationships between post-COVID-19 corporate strategy and innovation in developing countries. The objectives of the study are: (1) to analyse the current state of work on the research problem; (2) to develop and implement a methodological framework; and (3) to interpret the results obtained.

2 Research methodology

2.1 Research design

The present study is focused on finding an optimal set of instruments to facilitate the interaction between the innovations and corporate strategies in the corporate sector of China, as a way to increase their sustainability and further development. The main task of achieving the goal of the current research is to analyse the already existing models of corporate strategies in Chinese companies and check the degree at which their innovative capacity is being used. The next task is to propose the hypothesis that will allow to strengthen the use of innovations in China's corporate sector and contribute to the positive corporate structure development of the country. The research itself started by using the null hypothesis to figure out the main issues and proceeded then with the alternate hypothesis in order to make the predictions for the variables' connections and thus come up with the new hypothesis original to the present research. In order to make it possible, the acceptability, normality and reliability analysis have been applied so that it will be possible to specify the degree of the target groups' intervention in the survey for the ultimate new hypothesis, as an instrument to meet the requirements of the corporate sector in terms of innovations' application, the extent of possible burdens, the forecast efficiency, intervention coherence, opportunity costs and self-efficacy. Finally, for determining the degree of the statistics' correlation and predictability between the variables under analysis the bivariate distribution method was applied.

According to the results of the theoretical literature review, a unified method for investigating the mutual influence of corporate strategies on innovation is lacking. This study is an attempt to fill this gap. In this research project driven by a quantitative approach, the primary information came from a structured online survey.

This study focuses exclusively on Chinese firms. There are two primary reasons why: (1) China is a transition economy with many enterprises operating in a specific business environment; and (2) companies in China are accessible for and interested in research.

The sampling procedure involved selecting 6,000 random non-state-owned firms from the State Administration for Industry and Commerce (National General Administration for Industry and Commerce, 2022). The sampling was done as specified in Hermundsdottir et al. (2022). Managers and/or business owners were invited to participate in the study by email. The invites were sent out in November 2022, but some emails bounced back, indicating that the contact information was no longer valid. A substantial portion of the invites remained unanswered for unknown reasons or rejected. The main explanation for the reduced number of the ultimately-filled questionnaires is linked to the post-Covid-induced limitations and is subject to the current market situation to be considered as a part of the research findings. A total of 424 valid questionnaires were returned (N = 424), giving a response rate that falls within the range of 14% to 19% recommended by Haneberg (2020).

The questionnaire form employed here was developed using constructs from previous studies (Caloghirou et al., 2022; Hermundsdottir et al., 2022). It consists of 2 sections, which are the profile of the respondent (in our case, a Chinese firm) and data on innovation

and strategies. The questionnaire includes closed-ended single-choice items, open-ended items, and combined items with "Other" as one of the answer options. To ensure respondents understand the questions, the questionnaire form was validated through a preliminary assessment by industry practitioners and domestic researchers.

The questionnaire was written in Chinese. It has 18 items divided into two sections: respondent profile with 7 items and analytical section with 9 items. The respondent profile includes the following items: year of establishment of the firm (Q1), form of ownership (Q2), respondent's position at the enterprise (Q3), sector in which the firm operates (Q4), firm size (number of employees) (Q5), profitability dynamics (Q6) and employment dynamics (Q7). The analytical section includes questions about the relationship between corporate strategies and innovation.

2.2 Basic research methods

The study has been done using the traditional strategy of data compilation and analysis. The data was collected using a structured questionnaire. At the primary data processing stage, large data sets were reduced to a convenient size through encryption. The data analysis procedure involved a set of general scientific, econometric, and economic-statistical research methods, including correlation, structural analysis, and two-dimensional distribution. The item-total correlation method was used to assess the normality and acceptability of items. The results were interpreted using the graphical data presentation method. All operations were done in Microsoft Excel.

2.3 Research limitations and ethics of research

The study has several limitations. First, some email addresses used to invite respondents turned out as invalid. Furthermore, a considerable portion of firms did not respond to an email invitation; the reason is unknown, although is considered to be tightly connected to the post-Covid-induced volatility and changes in the market, leading the enterprises to the situations of being wound-up or relocated.

Second, many business executives who responded to an invitation did not want to participate in the survey due to data leakage concerns. Other limitations include low budget and time constraints, based on the necessity to continue the research in the circumstances when waiting for the companies' response or travelling to their potential present location would take up too much time and money and thus would be considered unviable. Note that the timely adjustment of the questionnaire form made it possible to minimize the impact of the second limitation.

All the materials and data under the analysis in the present articles are available in public access and subject to no copyright, thus there is no conflict of interest in the authors' developments.

3 Results and discussion

3.1 Results

It is obvious that global trade is being transformed by the digital economy and thus new possibilities emerge for enhancing the competitiveness on the international level for exporters and importers. However, these relationships are not homogeneous, they cover different layers of the economy including the digital economy development and resource allocation efficiency, as well as the expert enterprise markup. These are subject to regional modifications, which are mostly visible nowadays in the Eastern countries, China being among them. Thus, rather remarkable improvements are quite visible in those regions due to the fact that the level of technology and capital are being intensified in both government-controlled and non-state companies, and the crisis only contributes to boosting the markup of the expert enterprises nowadays (Yuan et al., 2025). Lately, there has been a lot of attention from the world community towards corporate social responsibility consisting of the financial and non-financial elements of management, including employee care supplier management, corporate governance, environmental management and risk management in social welfare activities and corporate operations. This results in much closer attention being paid to implementing more transparency for the operational activities of the companies, thus requiring the operating value of corporations to be reestablished with a focus on the principles of sustainable development (Li & Lee, 2024). In this connection, there is a call for understanding the extent of corporate image and social responsibility for the sake of consumer engagement in sustainable consumption in China. The conducted survey has allowed us to understand a number of patterns and processes in this respect.

The survey questionnaire was made up of 14 major questions aiming at collecting enough data representing the firms' patterns from the point of view of their overall operational history, employment, business area and innovative development patterns in order to figure out the current trends and perspectives in this field. In the survey, most respondents were firm owners (40%) or top managers (59%). Only 1% of the respondents chose the "Other" option. Of these, half said they were "deputy directors" and thus had sufficient competence to participate in the research project. Respondents were primarily from small and medium-sized firms in 4 sectors: manufacturing (53%), trade and services (40%) and agriculture (7%).

The respondents' perception of the link between individual strategies (Q7 to Q10) and their firm's business activity was assessed on a 5-point Likert scale, with higher scores corresponding to a better assessment (the exact wording of the items is available in Tab. 1). The subjective assessment of the effects of a strategic change ranges from 1.99 to 4.01 (Tab. 1). The item-total correlation coefficients of more than 0.4 indicate a high correlation and assume the normality and reliability of the sample.

The COVID-19 impact on the implementation of innovation (Q11 to Q14) was assessed in a similar fashion (the exact wording of the items is available in Tab. 2). The subjective

Tab. 1: Analysis of acceptability, normality, and reliability of the sample for Q7, Q8, Q9, Q10

No.	Items	Mean value (μ)	Standard deviation (σ)	Item-total correlation (r_{xy})
Q7	Product diversification strategy had a major impact on the business activity of our company in 2020–2023	4.01	0.84	0.49
Q8	Merger and acquisition practices had a major impact on the business activity of our company in 2020–2023	2.62	0.98	0.59
Q9	Geographical diversification strategy had a major impact on the business activity of our company in 2020–2023	1.99	0.81	0.46
Q10	Sustainable development strategy had a major impact on the activities of our company in 2020–2023	3.94	0.79	0.50

Source: own

Tab. 2: Analysis of acceptability, normality, and sample reliability for Q11, Q12, Q13, Q14

No.	Items	Mean value (μ)	Standard deviation (σ)	Item-total correlation (r_{xy})
Q11	Before the COVID-19 pandemic, our company was actively innovating in different areas	3.96	0.8	0.53
Q12	Our company is actively innovating during the post-COVID-19 period	3.00	0.82	0.49
Q13	In times of crisis, innovations are of secondary importance to development	2.03	0.82	0.47
Q14	A limited range of investment options during the crisis hampered the adoption of innovations	3.90	0.81	0.51

Source: own

assessment of innovation effects from the crisis ranges between 2.03 and 3.96, with a standard deviation of less than 0.82. The item-total correlation coefficients for each innovation-related item exceed 0.4, indicating a high correlation, as well as normality and reliability of the sample.

The research hypotheses were tested using the bivariate distribution method. Results show that private and limited liability firms were stimulating innovations more actively during the post-crisis period compared to companies with other types of ownership. Specifically, the percentage of respondents who chose positive options for items Q11 and Q12 was 19.3% and 23.2% higher among private and limited liability firms, respectively, than joint-stock companies. Such variation in the stimulation of innovation activities likely stems from the different decision-making and approval procedures deployed at the studied firms. This refutes the first research hypothesis (*H1*).

The analysis of bivariate size distribution failed to reveal significant differences in responses. Hence, the second research hypothesis (*H2*) can be considered confirmed. In this connection, it is appropriate to claim that the bivariate data has been rather properly collected and analysed, turning the response variables into the proof of a strong relationship between the explanatory and response variable, thus making the obtained data independent, quantitative, continuous, and ultimately demonstrating that it possesses a bivariate normal distribution. It shows how important it is for the corporations in China to combine innovations with the core corporate management values, such as team development, constant research, feedback implementation, active planning and evolution of the business strategies. While most innovative activities are currently available to be achieved by the AI-implemented tools, the team education is necessary for both top management and the employees of the corporation, as well as the shareholders, to be done in a combined manner, striving for the interaction between the conventional and innovative approaches. The statistics discovered in this research allows to understand that shareholders' involvement into the innovative process has a slow, but confident tendency to increase, regardless of the post-Covid crisis challenges, although deeper research is yet to be conducted.

Sustainable development and innovations go hand in hand at any stage of economic development, and there is a call for creating and utilising special facilitators for the development to follow the principles of sustainability, special economic policies can be created for this purpose in order to motivate different corporations comply with the goals of sustainable development that are largely discussed at the basis of the 2030 agenda around the world, as well as include the attempts to get rid of a number of regional inequalities connected to different forms of sustainable development which occurred due to the disproportions of innovation levels (Chaparro-Banegas et al., 2024). Therefore, the innovation activities in China are subject to the increased need for innovation stimulation and the results of this research have demonstrated certain trends.

The two-dimensional (2D) sectoral distribution revealed no significant differences in the stimulation of innovation activities between manufacturing, trade, and services firms. The agricultural firms, on the other hand, were much less active in post-crisis innovation activities (i.e., the value is 27.3% below the average). Hence, the third research hypothesis (*H3*) can be rejected (Fig. 1).

It is obvious that the companies operating in the field of agriculture currently seem to be lagging behind the other major sectors of economic activities as per the extent to which they invest their time and funds in the improvement and development of the modern technologies, hence their present innovation-connected design is not catching up with the others, yet can be largely considered as the most promising, possessing a huge potential of innovative activities and further projects to be invested in.

In addition, start-ups and new firms (those less than 5 years old) were stimulating innovation more actively compared to older firms that have been around for more than 5 years; the difference is 14.7%. This finding confirms the fourth research hypothesis (*H4*) that the stimulation of post-crisis innovation activities depends on the FLC stage. Firms prioritising diversification strategy were the most active in terms of innovation, while those focusing on mergers and acquisitions were the least involved. This finding confirms the fifth research hypothesis (*H5*). Note that the overwhelming majority of respondents disagreed with the statement that "innovation is of secondary importance during the post-crisis period,"

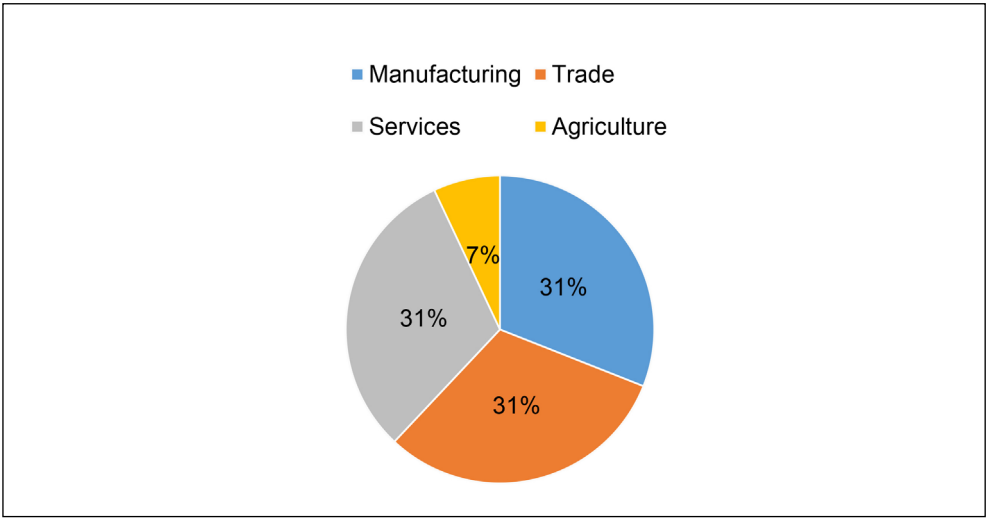

Fig. 1: **The ratio of the companies developing innovations in China in the post-crises period by sectors**

Source: own

assuming that innovation is a prerequisite for sustainable development.

The research has clearly demonstrated that innovation incentives can be pretty similar in manufacturing, trading and services, even though post-crisis innovation definitely is prioritised mostly in the trading area. The old market pending the introduction of innovative ideas is losing in front of the younger companies, which is the point for further discussion and urgent measures calls for extra measures to be taken in the near future.

The creative approach in management for innovative ideas and steps is a prerequisite for motivating the companies to utilise more frequently and deeply the post-crisis innovation schemes and instruments through the multiple and eclectic strategy implementation. Modernisation and creative management at the level of leadership are to be considered one of the pillars for further modernisation of the companies operating at different levels. The strategy of innovation in developing countries in the post-COVID-19 period so far has not been used to its full potential, as the example of China shows. The companies of different levels and sizes appear to be in relatively similar positions speaking of the need to combine and diversify the innovations strategy for their further development, through the practice of takeover and combined cooperation.

3.2 Discussion

Given the significant role of innovation and strategy in corporate development, it seems vital to understand the relationship between these two elements (Chen & Hao, 2022; Hao et al., 2023; Javeed et al., 2022). The current research project offers a methodological framework developed specifically for this purpose that draws upon a small number of recent studies. One such work explores the impact of COVID-19 on environmental innovation in manufacturing companies (Hermundsdottir et al., 2022). Note that despite considerable attention to strategy building in the time of the COVID-19 crisis, Hermundsdottir et al. (2022) focused more on environmental aspects. By comparison, the present study looks at the link between innovation and post-crisis strategy in general. Another study addressed the influence of corporate strategy on innovation with corporate risk as a mediator (Li et al., 2021). The COVID-19 effects were overlooked, however.

The effects of sustainable corporate strategy amid the COVID-19 pandemic were previously explored by Jílková (2021). By spacing the observation times apart (wave 1: March 15 to April 15,

2019; wave 2: March 15, 2020, to April 15, 2020), Jílková (2021) enabled the comparison of employee perceptions of the benefits provided to them before and after the COVID-19 pandemic. Unlike Jílková (2021), who focused on the human capital effects of a sustainable post-crisis strategy, the present study addresses the innovation perspective. It has been discovered that the increasing demands that the society of China poses to the economic development in general and corporate culture and activities in particular, changes considerably the patterns of their consumption and can ultimately lead to better conditions of the economic climate and the environment at the same time. A positive corporate image and social responsibility, involved in the huge companies' operations, can be called by far the most important factors that allow consumers in Chinese society to get involved in sustainable consumption. Obviously, the corporate image of any huge enterprise plays one of the most outstanding roles when it comes to appealing to the customers and trying to keep them for as long as possible within the company's operational domain. The corporate image is a basic concept that plays to the creation of the consumers' perceptions of the company using different direct and indirect instruments. (Streimikiene et al., 2024). The acceptability, normality and reliability analysis have demonstrated the increased awareness of the Chinese corporate shareholders and stakeholders regarding the connection between the degree of innovative initiatives and the corporate culture development. Using the quantitative and qualitative research, it has become evident that sustainability in the newly-emerged situation in non-state corporations of China largely depend on the level of intensity that the interactions with all the market participants can be achieved, regardless of their current economic state. The hypothesis having appeared and verified in the present study prove the emergence of an exclusive type of corporate culture development in the Eastern countries, such as China, therefore giving way to a new bend of their economic development for the time-being. The speed which China has been applying technologies to their development of logistics with, and the interactions between different fields of economy, apparently have considerably transformed the speed of the economy in general. Nevertheless, it was not enough for the overall positive image of the economic development, because it lacked sustainability, which was largely based on the restrictions, connected to the carbon emissions and many other efficiency tools that are connected to not only the industrial pattern and design of the economy, but also with the high-quality development of the environmental protection methods (Zhou et al., 2024). Corporate strategy and innovation depend a lot on the basic principles typical not only for China, but for the world economy as a whole, and this includes taking care of the end-of-pipe solutions and reducing the carbon footprint through the development of modern technologies, that can ultimately form not only the corporate culture for every particular enterprise, but also give a solid ground for the long-term sustainability in every sector of the country's economy, that keeps being integrated into other regions and the global structure. In this connection, there is a very important layer of research that has to be done connected to the development of the Innovations of business models that are based on responsibility and sustainability. The so-called stakeholder theory and stakeholder approach signifies looking after all the participants of the enterprise's activities, based on their location around the facilities and operations the company has in the area, as well as the shareholders' concerns. Profit will always be the most important motivation for any company to run, yet the community is supposed to be taken into consideration to a larger extent from now on. Thus, the responsibility of innovation is on the verge of being followed, in addition to the technological innovations that are already being applied everywhere in modern economic activities of China. This will result in further progressive opportunities for the country to have the leading positions in the world economy for many years to come. The inclusiveness and business ethics alone as the basis of a responsible stakeholder approach are irrelevant for these circumstances and have to consider all the third parties through the correction of the company's behaviour and methods of achieving their financial and managerial success (Magni et al., 2024).

Despite substantial research on the relationship between corporate strategy and innovation, this study put forward hypotheses that have not been previously tested by empirical evidence. In addition, it provides data that partially confirms or refutes previous findings. The results

of this study can expand our knowledge regarding the relationship between corporate strategy and innovation during the post-crisis period, enabling the development of adequate solutions for reviving the real economy after the COVID-19 crisis.

Conclusions

This study sought to identify the mutual effects of corporate strategy on innovation in developing countries during the post-COVID-19 period. The research hypotheses are that the stimulation of post-crisis innovation activities does not depend on (*H1*) the ownership of the firm, (*H2*) its scale of operation, (*H3*) and industry but on (*H4*) the firm's life cycle stage and (*H5*) the strategy complexity level. The survey of nearly 424 firm owners, managers, and deputy directors revealed that private and limited liability firms were stimulating their innovation activities more actively after the COVID-19 crisis when compared to joint-stock companies. The percentage of respondents who chose positive options for items Q11 and Q12 was 19.3% and 23.2% higher among private and limited liability firms, respectively than among joint-stock companies. This finding refutes the first research hypothesis (*H1*). The fact that there were no significant differences between firms with different scales of operation confirms the second research hypothesis (*H2*). While the manufacturing, trade and services firms exhibited similar levels of innovation activity, agricultural firms demonstrated lower values (27.3% below the average). Therefore, the third research hypothesis (*H3*) can be considered refuted. The empirical evidence suggests that start-ups and new firms (those less than 5 years old) were stimulating their innovation activities more actively after the COVID-19 crisis compared to firms older than 5 years (14.7% below the average). This finding confirms the fourth research hypothesis (*H4*). The bivariate distribution shows that the highest level of innovation activity is associated with deploying a diversification strategy, and the lowest level of innovation activity is supposedly linked to merger and acquisition practices. This finding confirms the fifth research hypothesis (*H5*). To sum up, the first and second hypotheses (*H1* and *H3*) were empirically proved to be false, and the remaining hypotheses (*H2*, *H4* and *H5*) were confirmed.

To expand this research, further analysis is to be conducted, mostly based on the theories of triple helix, quadruple helix and quintuple helix. This will allow us to extend and expand a lot the research done in this article and enlarge the understanding of the models of innovation economics, that present civil society and the environment as the most important and basic pillars and focal points of any policy, as well as practice and emphasise that the civil society complements their top-down government initiatives and industry policies and practices regarding the inclusive role of the sustainability priorities for the stakeholders and they environment, on the one hand, and figure out how this leads to smart, sustainable and inclusive growth. Further research based on triple helix, quadruple helix and quintuple helix theories is bound to help more in highlighting the rule that the natural environment of the society and sustainable development in the frames of expanded knowledge and innovations are the leading drivers for the production of that knowledge and innovation, as a definition of opportunities for the knowledge society and knowledge economy. Therefore, the models of knowledge, necessary for a more profound understanding of the link between corporate strategy and innovation in developing countries, will show a deeper connection between the models of knowledge in the sustainable development of a particular country on a global scale.

Implications. The present findings can be used to inform corporate strategy decisions in the real sector of the economy after the COVID-19 crisis. They also serve as a platform for further research. The most promising areas of research, in this case, are priority innovations in different strategic scenarios, factors influencing the innovation effects of corporate strategies, and the impact of corporate strategy and innovation on competitiveness in a post-pandemic world.

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Leading the greening: Assessing leadership attitude towards green policies, green environment, and the green circular economy

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Abstract: *Developing nations struggle to adopt and implement green initiatives in order to reach a circular economy. This study examined how leadership's green attitude directly affects green policies, the green environment, and the green economy. Additionally, this study considers the mediating role of green policies in achieving green environment and green economy objectives by using transformational leadership theory. The data was collected from the management-level employees of a public-sector telecom company via email using a time-lag approach. The data was analyzed using Smart PLS 4.0. The results revealed that leadership's green attitude affects the formulation and implementation of green policies in the organization. The leadership attitude also has a significant positive effect on the environment of organizations and contributes to a green economy. The empirical results show that green policies play a significant mediating role in enhancing a green environment and economy. This study has far-reaching consequences for corporate leadership and for the circular economy. It emphasizes the importance of proactive green actions done by leaders through the formulation and implementation of green policies. These actions not only boost the organization's long-term viability but also contribute to the nation's overall economic prosperity. The study's theoretical contributions to transformative leadership and sustainable development provide a new path to accomplishing sustainable development goals.*

Keywords: *Leadership green attitude, green policies, green environment, green economy, circular economy, sustainability.*

JEL Classification: *Q01, Q50, Q56, D02, M10, M12, M14, O10, O13, O15, L29.*

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Introduction

The shift to a circular economy requires appropriate policies, strategies and actions. Green policies and decisions are practiced in developed countries to support economic growth. However, backward countries are facing problems with the implementation of green policies (Wu & Cao, 2021). The existing studies in the literature disclosed different dimensions of green policies and the green environment (Alyahya et al., 2023; Tao et al., 2022; Wang et al., 2022). According to some authors, green policies are necessary for organizational change, but employees should be motivated by the adoption of these policies (Hemanand et al., 2022; Heydari et al., 2021). On the other hand, when employees are not motivated, they would not be happy to adopt the sustainability goals in their organizations. The organizational culture is required to be improved over time, and multiple strategic actions should be taken to improve the working of the employees for development and productivity (Luu, 2022). Motivated employees would contribute to a sustainable future, which should be supported by the organizational culture. Many modern organizations are productive in their work because of their high-quality employees' performance for achieving sustainability. Green economic policies have emerged as a crucial approach to address environmental challenges while promoting sustainable economic development. Recently, the green economy has become a global trend, stimulating extensive research and debate. It encompasses various aspects, including circular economy principles, green environment, and green transformational leadership.

The impact of green policies is improved when the organizational working is strong and the employees are motivated to adopt these policies for their work (Salman & Wang, 2024). Pakistan is a third-world country facing a crisis related to the sustainability of the environment. The economic policies of Pakistan have not been appropriately developed to support its economy (Qi et al., 2023). Environmental degradation continues in modern times, despite different actions taken to support environmental improvement. The mismanagement and lack of policy implementation are considered the major restrictions towards green policies. The countries that are using sustainability-related policies are working in a better direction to achieve policies for environmental sustainability. The lack of strategic management is also one of the reasons the green policies are not being implemented in Pakistan.

Sustainable development in any organization is the way forward to get the basic requirements fulfilled for the economy and environment. The role of management is to implement strategic planning and take sustainable actions. However, the management of Pakistan Telecommunication Company Limited (PTCL) is facing challenges regarding the implementation of strategic goals to achieve sustainability (Zubair et al., 2025). As a leading telecom company in Pakistan, PTCL has taken significant steps towards green policies, but it is still facing issues in the strategic implementation of the goals for sustainability (Husain et al., 2024). Similar to other organizations in Pakistan, leadership of PTCL is not sharp enough to fulfill the sustainability goals. Hence, sustainable working for a green economy and green environment by PTCL is neglected, and it is only in documents and not properly practiced.

Therefore, the objective of this research is to determine the impact of leadership green behavior on green policies, green environment, and green economy by focusing on PTCL. This research addresses the visible gap in the literature, not highlighted by past studies. The findings of this research are critical for advancing the working of employees based on green policies to achieve sustainability in the organization. The theoretical implementations developed by this research are also significant as the newly developed relationships are introduced in the literature. The future directions proposed by this research can pave the way for further studies in the fields of green economy, leadership, and green policies needed for the transition to a circular economy.

1 Theoretical background

This study is based on the transformational leadership theory, suggesting that leadership is the key to transforming the organization from one situation to another (Gigauri & Khan, 2025). It advocates that leaders who are inclined towards the introduction of best practices at their work, lead their organization into a new way of change for advancement. Through the integration of these new work practices, they devote effort to transforming the organization. Transformational leadership theory can drive PTCL's green policies by inspiring

employees, fostering innovation, and integrating sustainability into its vision. Leaders can act as role models by prioritizing renewable energy and eco-friendly solutions while motivating employees through awareness campaigns and incentives (Ashraf et al., 2024). By encouraging innovative green telecom solutions and investing in employee training, PTCL ensures effective implementation of sustainability initiatives, making it a leader in environmental responsibility within Pakistan's telecom sector.

Organizational culture has a significant interplay with the leadership role; however, leaders require adequate resources to introduce practices that transform the working environment. This study highlights that the attitudes of the leaders are the key factor that facilitates the organizational transformation to becoming green, leading it towards a positive change. The study framework (Fig. 1) reflects the significant association between leaders' attitudes and the organizational inclination towards green policies, transforming it into a green economy and environment, based on the premise of transformational leadership theory (Farrukh et al., 2022). The study includes leadership green attitude as the independent variable influencing the green environment and green economy as the dependent variables, mediated by green policies created by the leader. According to the leadership transformational theory, the leadership green attitude represents the leader's feelings often expressed through the behavior, whereas the green environment and economy represent the transformational change taking place in response to the leader's green attitude towards the green policies.

1.1 Leadership green attitude and green environment

A green environment is necessary for any country, but it can be achieved by the sustainable performance of organizations (Begum et al., 2022). The relationship between leadership that exhibits a pro-environmental mindset and its positive impact on fostering an ecologically conscious atmosphere is a subject that is gaining prominence in the fields of environmental sustainability and leadership studies. Leaders who embrace an environmentally conscious attitude are individuals who prioritize and push the adoption of environmentally responsible practices within their particular organizations. This perspective is exemplified by a variety of initiatives, such as the promotion of energy efficiency, the minimization of waste, the endorsement of sustainable procurement, and the facilitation of environmentally friendly activities (Mogende & Ramutsindela, 2020). Leaders with an environmental attitude can inspire their teams to adopt environmentally responsible behaviors, thereby championing initiatives such as recycling campaigns, carbon footprint reduction, and the incorporation of sustainable business processes (Zheng et al., 2023).

H1: Leadership green attitude has a positive impact on a green environment.

1.2 Leadership green attitude and green policies

The success of the organization and its performance is a productive way to improve organizational performance, while the role of leadership is to support the employees by developing green policies. Leaders with a pro-environment mindset advocate for environmentally friendly measures and values. These leaders' influence on the development of policies that support sustainability can be considerable. The above association is supported by existing scholarly works that emphasize the critical role of leadership in driving environmental policy attempts (Yin et al., 2023). Furthermore, scholarly research into the relationship between leadership styles and the formulation of environmental policies indicates that transformational leaders play an important role in instilling inspiration and motivation within businesses and communities, thereby facilitating the adoption of environmentally sustainable practices. Leaders with transformational skills and a strong commitment to environmental sustainability are capable of effectively communicating the relevance of sustainable practices. As a result, these leaders can help to design policies that encourage and prioritize environmental stewardship (Riva et al., 2021). Indeed, the access of employees to green policies and support from the leadership can motivate them to develop their green behavior effectively.

H2: Leadership's green attitude has a positive impact on green policies.

1.3 Leadership green attitude and green economy

The relationship between environmentally friendly leadership and its favorable impacts on the promotion of a sustainable economy is

an important topic in the disciplines of environmental sustainability and leadership studies. Leaders who are deeply committed to environmental stewardship prioritize the implementation of sustainable practices and concepts. Contemporary research studies that emphasize the critical importance of leadership in advancing ecologically sustainable economic activities support the aforementioned relationship (Ma et al., 2024). According to Begum et al. (2022), leaders with transformational abilities and a commitment to environmental sustainability can inspire both organizations and communities to adopt sustainable practices. This, in turn, has the potential to lead to economic growth through ecologically responsible tactics and innovative ways. The inclusion of environmentally conscious leadership is critical to the growth of green entrepreneurship, innovation, and investment. Leaders who advocate for sustainability have the capacity to push both businesses and individuals to dedicate resources to green technologies and environmentally responsible undertakings (Gatell & Avella, 2024). This ultimately can lead to promoting economic growth while also reducing environmental deterioration.

H3: Leadership green attitude has a positive impact on the green economy.

1.4 Green policies and green environment

The modern market requires a green environment and working policies that are necessary to be implemented reasonably (Aftab et al., 2022). Furthermore, the success of green organizational performance is a possible way to achieve a green economy. However, it is not only the responsibility of the small or public sector organizations but the corporate sector organizations are also required to achieve green sustainability goals. Evidently, working ethics can be achieved when the organizational work is based on green environmental policies (Ling et al., 2022). The role of green environment policies supported by organizational leadership can be a strategic way to advance green success in the market. The reliability of green services helps people to improve green behavior. In order to achieve sustainability, organizations are required to implement green strategies and contribute to a green environment. Furthermore, green management policies and practices facilitate organizational development and success in the market (Obrecht et al., 2022). Concurrently, the valuable instructions regarding green policies can motivate employees to strive for a green environment and sustainability. In this regard, the transformational leadership theory emphasizes the role of green policies for organizational performance to support a green environment.

H4: Green policies have a positive impact on the green environment.

1.5 Green policies and green economy

The green policies ensure that the employees and organizational functioning comply with organizational standards (Koval et al., 2022). The availability of green and reliable resources facilitates organizational productivity and effectiveness in advancing green policies (Alyahya et al., 2023). The management support for the adoption of green policies can be successful in implementing green policies in the green organization (Khan et al., 2023). The level of green environment and green success can become a possible way to achieve green sustainability. Furthermore, the transformational leadership theory supports green policies for organizational green performance. Organizations' green policies influence the organizational climate for the green behavior of employees. In this context, green policies may significantly contribute to the green economy.

H5: Green policies have a positive impact on the green economy.

1.6 Mediating role of green policies

When the leadership of the organization is self-motivated to achieve green sustainability, and the employees are working hard to achieve it, the success rate of the organization is improved (Kunapatarawong & Martínez-Ros, 2016). The reliability and successful implementation of green policies increase when employees have the adaptability and acceptance to achieve a green environment (Khoshnava et al., 2019). The employees cannot achieve green behavior when they are not treated fairly. Compensation to the employees for their green behavior is also required to ensure their green performance (Liargovas et al., 2017). The leadership's green attitude motivates and encourages their sustainable behavior towards a green environment. According to transformational leadership theory, the role of leaders is necessary in the transformation of the organizations. This research conceptualized that

green policies developed by the leaders are facilitating them to achieve a green environment.

H6: Green policies positively mediate the relationship between leadership green attitude and green environment.

The organizational goals for sustainability are achieved when the performance of employees is shaped by green behavior. Those employees who are not motivated for strategic performance, are required to have organizational culture awareness (Dauvergne, 2022). The top management of the organization is required to work on the sustainability policy to improve the performance of the organization for green working and a green environment. The strategic way to improve the environment in the organization is possible with green attitudes. The successful development of organizational culture helps the management to achieve the organizational goals (Bayulken et al., 2021). The management of modern organizations should have green policies to implement sustainable goals. The leadership of the organizations is required to motivate the employees for green attitudes (Mohsin et al., 2022). The sustainability of the environment is possible when all-level management works towards organizational goals of the green economy.

H7: Green policies positively mediate the relationship between leadership green attitude and a green economy.

Hence, based on the above literature the research framework is developed (Fig. 1).

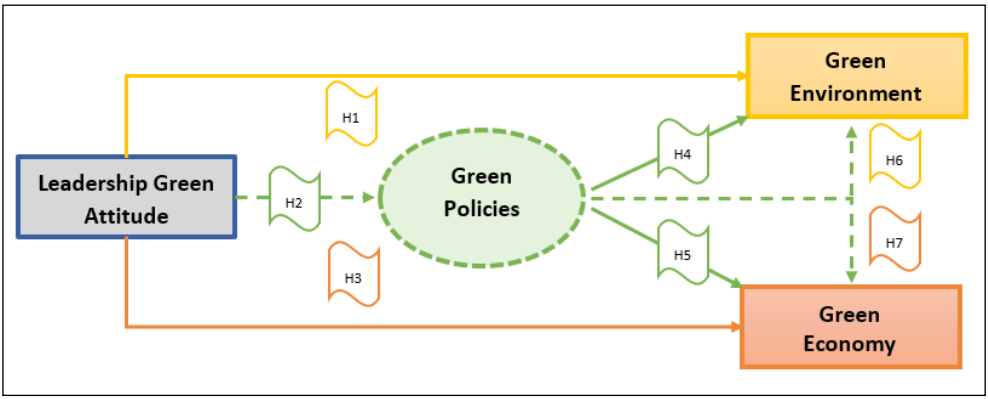

Fig. 1: Theoretical framework

Source: own

2 Research methodology

2.1 Measurement items

This research has used the primary data for the empirical test of the relationship between the variables hypothesized in the previous sections. The quantitative data was collected through the self-administered questionnaire adopted the Likert scale based on 7-points considering "strongly disagree" to "strongly agree."

The scale items were adapted from the existing studies with modifications to fit in the context of the current research. The validity and reliability of the scales were confirmed by the Cronbach alphas, composite reliability values, and factor loadings of the items. The measuring items for leadership green attitude were adapted from Khan and Khan (2022), considering its Cronbach alpha values of 0.88, composite reliability values of 0.91, and factor loadings for all items above 0.66. Next, the scale items for green policies were adapted from Cheema et al. (2015), demonstrating Cronbach alpha values of 0.78, composite reliability values of 0.87, and factor loadings for all items above 0.71. The scale items for measuring the green environment were adapted from Juliana et al. (2020) with

Cronbach alpha values of 0.81, composite reliability values of 0.70, and factor loadings for all items above 0.69. Lastly, the scale items for measuring green economy were adapted from Kunapatarawong and Martínez-Ros (2016) confirming Cronbach alpha values of 0.77, composite reliability values of 0.73, and factor loadings for all items above 0.67.

2.2 Population, data collection and sample size

A public sector telecom company, Pakistan Telecommunication Limited (PTCL), providing services in all parts of the country, was selected for the study keeping in view the initiatives taken by them for green working. The data was collected from the company's managerial workforce using random sampling techniques. The request for participation in the study was sent to managerial-level personnel only keeping in view their leadership roles and responsibilities. The authors approached the human resource department of PTCL head office for data collection. The HR department subsequent to top management approval, distributed the questionnaire to the management-level employees across the country through their intranet. The purposive sampling technique was used in time lag approach for data collection and the questionnaire was sent in four different phases based on the regional divisions. Purposive sampling allows to select participants based on specific characteristics relevant to the study, ensuring that the data collected is highly targeted and meaningful. While the utilization of the time lag approach in data collection via email conferred numerous advantages by offering convenience and adaptability for the involved parties (Bell et al., 2018). Also, the utilization of the time lag approach in collecting email data served to reduce the impact of social desirability bias. The respondents were given the chance to engage in introspection and furnish more precise data without experiencing the immediate strain of in-person or telephonic interviews. Qi et al. (2023) suggested that the data collected using a time lag approach increases the likelihood of obtaining truthful and straightforward answers, augmenting the caliber of the gathered data. It took about 3 months for the data collection process with several reminders. A total of 398 responses were received and after initial screening, 7 responses were rejected due to a large number of missing values, resulting in 391 responses included in the final analysis.

2.3 Data analysis tool

The study applied Smart PLS 4.0 for data analysis. The data normality test, the measurement model assessments, the structural model assessment, and the predictive relevance were measured to assess the hypothesized relationships in the study. In measurement model assessment, the validity, reliability, and discriminant validity of the items were checked. In structural model assessment, path coefficient estimates, predictive relevance and its strength, and indirect relationship impact were calculated to determine the findings of paths in the study framework.

3 Results

3.1 Data normality test

The data normality test was undertaken before moving towards the structural analysis of the research framework. Usually, the data-normality is tested using different methods. However, the most used method to test the data normality is the skewness and kurtosis method. It helps to determine the missing values, mean standard deviation, and the values of skewness and kurtosis. As a rule of thumb, the findings of skewness should not be less than −1 and the findings of excess kurtosis should not be more than +1 for the normality of data (Royston, 1992). The results confirmed that the data normality was achieved (Tab. 1) with no missing values, confirming its suitability for further analysis.

3.2 Measurement model assessment

After confirming the data normality, the study proceeded with the measurement models' assessments to confirm their convergent validity. The factor loadings of each item of the scales were calculated and were found above 0.60, acceptable for further analyses (Shevlin & Miles, 1998). Next, the study checked the values of Cronbach alpha to determine the validity of the construct's scales. The values of Cronbach alpha above 0.70 confirmed its construct reliability (Tavakol & Dennick, 2011). Moreover, the composite reliability of the study constructs was also tested. The findings confirmed that the composite reliability findings achieved as the values are above the threshold of 0.70 (Hair et al., 2020). Next, the average variance extracted (AVE) was also computed

Tab. 1: Skewness and kurtosis results

Items	No.	Mean	Standard deviation	Excess Kurtosis	Skewness
LGA1	1	4.072	1.074	0.804	−0.167
LGA2	2	3.580	1.150	−0.334	−0.577
LGA3	3	3.957	1.055	−0.083	−0.787
LGA4	4	3.953	1.022	0.169	−0.826
LGA5	5	3.446	1.152	−0.472	−0.417
LGA6	6	3.580	1.128	−0.442	−0.504
GP1	7	3.609	1.185	−0.483	−0.569
GP2	8	4.446	0.956	0.874	−0.846
GP3	9	4.228	1.047	0.117	−0.344
GP4	10	4.014	1.173	0.497	−0.151
GP5	11	4.080	1.158	0.622	−0.211
GP6	12	3.935	1.153	0.197	−0.985
GEN1	13	4.069	1.122	0.673	−0.188
GEN2	14	4.123	1.090	0.908	−0.260
GEN3	15	3.793	1.259	−0.370	−0.800
GEN4	16	3.674	1.181	−0.449	−0.620
GEN5	17	3.989	1.048	0.354	−0.928
GEN6	18	4.065	0.998	0.507	−0.989
GEN7	19	4.025	1.037	0.616	−0.031
GEC1	20	4.058	1.051	0.654	−0.094
GEC2	21	3.978	1.110	0.284	−0.981
GEC3	22	3.793	1.105	−0.122	−0.733
GEC4	23	3.895	1.110	0.199	−0.910
GEC5	24	4.040	1.174	0.539	−0.171
GEC6	25	3.725	1.092	−0.214	−0.611
GEC7	26	3.826	1.122	−0.118	−0.797

Source: own

to determine the variance captured by the construct to validate it further. The acceptable threshold for average variance is above 0.50 (Hair et al., 2019). The findings confirmed that the average variance extracted was achieved for all the study variables (Tab. 2).

Subsequently, the discriminant validity was tested. The discriminant validity factor is used to test whether the measurements used for data collection for different variables are related or not, which should not be related with clear discrimination between them. The test determines the discrimination between the items by employing different methods. The current study adopted two significant methods of heterotrait-monotrait and measuring cross-loading to determine the discriminant validity of the study constructs. The heterotrait-monotrait method is a second-generation method to test this relationship. When the results generated using

Tab. 2: Convergent validity results

Variables	Items	Factor loadings	Cronbach alpha	Composite reliability	Average variance extracted
Green economy	GEC1	0.855	0.878	0.909	0.598
	GEC2	0.880			
	GEC3	0.849			
	GEC4	0.890			
	GEC5	0.770			
	GEC6	0.649			
	GEC7	0.612			
Green environment	GEN1	0.815	0.894	0.915	0.607
	GEN2	0.753			
	GEN3	0.805			
	GEN4	0.754			
	GEN5	0.761			
	GEN6	0.805			
	GEN7	0.758			
Green policies	GP1	0.665	0.878	0.908	0.626
	GP2	0.667			
	GP3	0.848			
	GP4	0.848			
	GP5	0.839			
	GP6	0.851			
Leadership green attitude	LGA1	0.655	0.846	0.887	0.568
	LGA2	0.705			
	LGA3	0.811			
	LGA4	0.832			
	LGA5	0.771			
	LGA6	0.733			

Note: LGA – leadership green attitude; GP – green policy; GEN – green environment; GEC – green economy.

Source: own

heterotrait-monotrait show that the values are less than 0.90, it confirms the discriminant validity of the constructs (Gold et al., 2001). The findings (Tab. 3) depicted values less than 0.90 thus confirming the study variables' discriminant validity using the heterotrait-monotrait method.

Next, the cross-loading method was run to reconfirm the discriminant validity of the study constructs. In the cross-loading method, the values of the measurements of one variable are compared with the values of the measurement of other items. For significant cross-loadings, the values of one variable's measurement should be greater than the values of measurements of other variables that are in correlation with it. The findings of cross-loadings reconfirmed that the study variables meet the criteria of discriminant validity (Tab. 4).

Tab. 3: **Discriminant validity results (heterotrait-monotrait method)**

Variables	*Green economy*	*Green environment*	*Green policies*	*Leadership green attitude*
Green economy				
Green environment	0.824			
Green policies	0.669	0.849		
Leadership green attitude	0.725	0.761	0.801	

Source: own

Tab. 4: **Discriminant validity results (cross loadings method)**

Items	*Green economy*	*Green environment*	*Green policies*	*Leadership green attitude*
GEC1	0.855	0.738	0.531	0.532
GEC2	0.880	0.690	0.532	0.538
GEC3	0.849	0.682	0.520	0.539
GEC4	0.890	0.717	0.520	0.540
GEC5	0.770	0.655	0.475	0.411
GEC6	0.449	0.323	0.261	0.342
GEC7	0.612	0.443	0.401	0.439
GEN1	0.548	0.815	0.756	0.576
GEN2	0.418	0.753	0.739	0.515
GEN3	0.610	0.805	0.717	0.610
GEN4	0.684	0.754	0.489	0.512
GEN5	0.778	0.761	0.478	0.455
GEN6	0.727	0.805	0.539	0.501
GEN7	0.759	0.758	0.483	0.483
GP1	0.594	0.566	0.865	0.743
GP2	0.246	0.415	0.667	0.415
GP3	0.420	0.643	0.848	0.499
GP4	0.461	0.634	0.848	0.520
GP5	0.482	0.687	0.839	0.489
GP6	0.580	0.747	0.851	0.617
LGA1	0.333	0.432	0.520	0.655
LGA2	0.446	0.436	0.428	0.705
LGA3	0.505	0.576	0.587	0.811
LGA4	0.505	0.603	0.640	0.832
LGA5	0.544	0.525	0.522	0.771
LGA6	0.472	0.458	0.491	0.733

Source: own

3.3 Structural model assessment

After the measurement models assessment, the study proceeded with the structural model assessment to determine the findings of the hypothesized relationships among the study variables. The *t*-values and *p*-values were calculated for the path results. The recommended method by Hair et al. (2020) is used to determine the findings for both direct and indirect paths. The one-tailed hypothesis is significant when the *t*-values are above 1.64 (Ramayah et al., 2018). Since this study has a directional and one-tailed hypothesis, the *t*-value above or equal to 1.64 is considered significant.

The structural path analysis findings confirmed the acceptance of hypothesis *H1* with *t*-value = 4.441, illuminating that leader's green attitude has a significant positive impact on the green work environment.

Next, the findings of hypothesis *H2* unveiled that a leader's green attitude has a significant positive impact on workplace green policies (*t*-value = 2.023). Thirdly, the findings of hypothesis *H3* also confirmed that a leader's green attitude has a significant positive impact on the green economy (*t*-value = 5.487).

Furthermore, the findings of hypotheses *H4* and *H5* disclosed that the leader's green policies have a significant positive impact on the green environment (*t*-value = 12.884) and the green economy (*t*-value = 4.538). The detailed report is provided in Tab. 5.

Subsequently, hypotheses *H6* and *H7* were tested to determine the mediating effect of the leader's green policies between his/her attitude and green outcomes in terms of economy and environment. The findings confirmed that the leader's green policies positively mediated the relationship between his/her green attitude and the green environment (*t*-value = 12.876), thus accepting hypothesis *H6*. Moreover, the findings also confirmed the significant mediating effect of the leader's green policies on the relationship between a leader's green attitude and green economy (*t*-value = 4.497), which accepted our study hypothesis *H7* as well. The mediation study results show that the impact of a leader's green policies on the green environment and economy

Tab. 5: Direct paths findings

Paths	Original sample	Sample mean	Standard deviation	*t*-statistics	*p*-values
Leadership green attitude → green environment	0.227	0.233	0.054	4.221	0
Leadership green attitude → green policies	0.710	0.711	0.035	2.023	0
Leadership green attitude → green economy	0.385	0.394	0.070	5.487	0
Green policies → green environment	0.634	0.632	0.049	12.884	0
Green policies → green economy	0.337	0.332	0.074	4.538	0

Source: own

Tab. 6: Indirect paths

Indirect paths	Original sample	Sample mean	Standard deviation	*t*-statistics	*p*-values
Leadership green attitude → green policies → green environment	0.450	0.449	0.035	12.876	0
Leadership green attitude → green policies → green economy	0.239	0.236	0.053	4.497	0

Source: own

is more significant and profound than the direct relationship. Tab. 6 presents the results of indirect paths.

3.4 Predictive relevance

The predictive relevance was also tested to establish the relevance of the endogenous constructs. The blindfolding method was adopted to determine the Q^2 values. When the values of predictive relevance are more than 0, it means there is predictive relevance of the endogenous constructs in the model (Koban et al., 2012). The findings depicted that Q^2 values of the constructs are more than 0, which confirmed the predictive relevance of path coefficients (Tab. 7).

Tab. 7: Q^2 results (predictive relevance)

Variables	SSO	SSE	Q^2 (= 1 − SSE/SSO)
Green economy	1,932	1,426.812	0.261
Green environment	1,932	1,205.951	0.376
Green policies	1,656	1,172.805	0.292
Leadership green attitude	1,656	1,656.000	

Source: own

4 Discussion

The findings of this study, conducted in the context of Pakistan Telecommunication Company Limited (PTCL), shed light on the significant influence of leadership's environmentally friendly attitude on the development of green policies, green environment, and green economic achievements. The existing empirical research supports the assumption that leadership commitment to environmental sustainability has a major impact on a variety of critical factors, both directly and indirectly. Our study demonstrates a substantial relationship between leaders' attitudes towards green policies and their positive influence on the organizational environment and contribution towards a circular economy. This conclusion is consistent with prior research by Aftab et al. (2022), which highlighted the importance of senior leadership in organizational situations. Leadership is generally connected with the ability to successfully utilize resources and encourage employees to exert a consistent level of effort. When leaders at all levels work together to achieve management objectives, it generates an atmosphere that has the potential to enhance the sustainability of the environment. The availability of an effective leadership style and the implementation of green policies enable organizations to achieve a green environment and contribute to a green economy. Furthermore, our findings are consistent with those of Ling et al. (2022), underlining the necessity of creating favorable conditions to encourage employee participation in environmentally friendly efforts.

In accordance with our second set of findings, our study reveals a significant relationship between leadership's green attitude and the formulation and implementation of green policies. According to Obrecht et al. (2022), worker success rates are impossible to achieve in any type of job until acceptance-related concerns are resolved. It is possible to determine a worker's achievement rate in their work by looking at how strictly they adhere to the goal of a green workplace. Whenever they are not compensated equitably, employees are unable to exhibit green behavior. Implementing a green circular economy is possible through employees striving towards sustainability, which is encouraged by leaders' green behavior. According to Dauvergne (2022), resilience is a key component of creating an environmentally conscious society, but organizational personnel also need to be inspired to strive towards it. In addition, the green environmental policies of businesses can support long-term growth, but management must put in the necessary effort. It would be challenging to attain green performance unless the top leadership is receptive to it. An effective technique to enhance organizational functioning is to evaluate the company's achievements.

Furthermore, the study found a significant relationship between environmentally conscious leadership and a positive impact on the green economy. According to Koval et al. (2022), the secret to working towards an environmentally friendly planet is tactical leadership. Additionally, all organizational management procedures for improved organizational advancement are necessary to achieve market success. Employees should be inspired to strive for sustainable development by receiving helpful guidance. Any organization must have green policies in place to guarantee that its personnel and operations meet organizational standards. According to Bayulken et al. (2021), the effectiveness of organizations in the market determines how successful their efforts at longevity will be. Making green resources available for organizational use can be a useful strategy for advancing green policy.

The study results confirm and build on prior research by highlighting the critical role of green policies in fostering environmental sustainability. According to Mohsin et al. (2022), it is necessary to work equitably to accomplish environmental goals in the proper direction for many organizations that have struggled to accomplish compatibility concerning the environment. In the present era, shaped by complexities of the volatile, uncertain, complex, and ambiguous (VUCA) environment, it is vital for companies to improve their organizational culture through green transformational leadership and implement green practices. According to Alyahya et al. (2023), the general population's exposure to green knowledge and culture can help companies reach the next standard for green policy. The effectiveness of green initiatives in any country depends on their achievements in creating a green environment. The importance of ecological sustainability can serve as a tactical tool for promoting the commercial popularity of green products. Implementing green policies in green organizations can be successful with managerial backing for environmentally friendly rules.

According to the findings of our research on the effects of green policies, the adoption and enforcement of such policies play a significant role in fostering the growth of a sustainable green economy. According to Amankwah-Amoah and Syllias (2020), the degree of environmental sustainability and green business performance may become a viable strategy. The green performance of an organization will improve if the organization's leadership promotes green policies and practices.

Lastly, the results of mediating variables show that green policies positively mediate the relationship between leadership's green attitude and a green environment. According to Mogende and Ramutsindela (2020), any organization working to promote environmental sustainability can succeed if every member of that particular team is driven to make a difference. It is also conceivable for the management to permit staff to work in a greener manner. Workers may be able to grow in their careers by adopting green work practices. Personnel who have access to green policies may be encouraged to practice green behaviors in a useful manner. According to Riva et al. (2021), the modern marketplace demands a green atmosphere and functioning policies that must be put into place in a just manner.

Conclusions

Developing an environmentally friendly economy is feasible through the achievement of green organizational functioning. Individuals who lack the drive to perform strategically must be aware of the company's culture. To increase the company's achievements for green functioning and an ecologically conscious setting, the top management must support an environmental strategy. Similarly, the findings indicate that green policies positively mediate the relationship between leadership green attitude and a green economy. Environmentally friendly working of an organization makes it feasible to strategically enhance the economic and environment sustainability and contributes to sustainable development goals. The organization's objectives should be set following the environment, with sustainability as its ultimate objective. To ensure that employees are working more effectively for the success of the company, it is also necessary to compensate them for their sustainable behavior. Leaders should provide the support and monitor employee performance to improve the organization's achievements for sustainable future.

Theoretical implications. This study has theoretical as well as practical implications that are new to the literature and practice. Firstly, this research introduced new relationships in the body of knowledge. The findings of this research empirically highlighted that the green environment is influenced by leadership

green behavior. This study also demonstrated in the literature that green leadership behavior is also an influencing variable to green policies. In the same way, the study highlighted that the green economy is possible with leadership green behavior. Furthermore, the study emphasized that the green policies within an organization significantly influence the green environment. The research strengthens academic knowledge by combining transformations leadership theory with sustainability research methods. Leaders expressing a green attitude enable policy development implementing green initiatives which leads to better sustainability at the organizational and national levels. The study brings leadership theory and sustainable development closer together which provides researchers and practitioners new methods to achieve circular economy goals along with sustainable development goals (SDGs) through greater understanding of transformational leadership practices in sustainability contexts.

Practical implications. The practical importance of this research is also critical as it has presented the ways that could be possibly used for the green economy and green environment achievement. The study has demonstrated that a green environment is a crucial factor that can be achieved when the organizational leadership is motivated to work to achieve it. Access to a green environment can improve the organization working in a green direction. The organizational policies developed for the achievement of green behavior can take the organization to a green economy. However, it is also noted that the leadership of the organization should be self-motivated to adopt green behavior. The implementation of green policies is the path towards the improvement of sustainable performance of organizations. The organizational culture should be transformed to support a green environment. Green transformational leaders can play a leading role in introducing green policies, creating a green environment, and achieving a green economy. PTCL's leadership group should adopt green policies through initiatives that support sustainable technologies like solar telecommunications towers and intelligent energy control systems which provide cost reduction and carbon emissions control. PTCL can develop an environmental work culture which meets both national and global sustainability standards through the use of sustainability-based practice incentives and employee training led by transformational leaders. The investment in green digital infrastructure contains paperless approaches and e-billing systems which yields advantages for both environmental sustainability and consumer satisfaction together with cost-efficiency benefits. PTCL can elevate its position in Pakistan's sustainable transition by implementing leadership-backed programs which both reinforce CSR performance and construct a positive brand image.

Limitations and future directions. This study has some limitations that may prompt further research. The study has identified the relationship between different variables and presented results. Yet, the research has collected data only from the respondents who are employees at the managerial level in one organization. Furthermore, the study has only targeted PTCL branches in the main cities of Pakistan excluding remote areas. Therefore, future studies should enhance the findings of this research by incorporating not only managers but employees as well, and by surveying other companies in diverse industries. Since leadership attitudes may differ among cultures, future research in different countries can be beneficial for the advancement of theory and practice. In addition, scholars can collect not only quantitative data but also use qualitative methods to further explore the phenomenon.

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New evidence on drivers influencing negotiation between financial auditors and their clients concerning resolution on the audit opinion. The case of an emerging economy

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Abstract: *Controversies concerning the main drivers of the auditor-client relationship have been discussed over time, although interest in this topic appears to have slightly declined, with recent studies mainly addressing auditors' competencies, independence, audit fees and quality of audit services. However, the current business environment shows significant concerns on the high level of economic uncertainty, and complexity of business models, even though auditors have shown interest in adopting emerging technologies. Within this VUCA-BANI framework, auditors are pushed to reconsider the implications of those transformations into their own capabilities, in order to provide adequate solutions to their customers. Instead, the auditor-client relationship does not relate only to discussion on the area of enhancing clients' or auditors' dynamic capabilities to become more resilient, and to ensure competitive audit fees, but also to a continuous communication process that influences the outcome of each assurance engagement, many times depending on a negotiation process aimed to limit auditors' liability and increase clients' satisfaction. The purpose of this study is to investigate the main drivers influencing financial auditors' choice for different negotiation strategies used during reconciliation meetings with clients. The research is based on a survey disseminated through active financial auditors from Romania. Following a robust theoretical framework, including the client-auditor negotiation dynamic theory, the research design consists of multivariate data analysis. This paper adds insights into the literature, on a topic that is mainly discussed in research settings consisting of highly developed economies, neglecting the specifics of emerging economies. The study aims to provide insights on drivers of auditors' choice for negotiation strategies and related tactics in the stage of meetings of reconciliation with clients. Research results indicate that the auditors' position of negotiation is significantly influenced by client pressure and the quality of the auditor-client relationship.*

Keywords: *Auditor-client relationship, power of negotiation, distributive negotiation strategies, integrative negotiation strategies, going concern.*

JEL Classification: *M42, M41, H83, G34.*

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Introduction

The relevance of the auditors within the business landscape along the time has been confirmed over the last decades, including from the perspective of the contribution to the value creation process across industries and value streams, via the increase of financial statements quality, forensic auditing, or business process improvements as well, which reduces the agency costs and financing constraints (Johri & Singh, 2024; Trotman et al., 2011; Ye, 2023). Scholars' research interest has also paid a higher attention to the assessment of the dynamics and characteristics of the auditor-client relationship, with a focus on ways of building trust and credibility, auditor independence, auditor tenure, or power dynamics between auditors and clients (Mustikarini & Adhariani, 2022).

Instead, the literature has not sufficiently addressed the topic of auditor-client negotiation process, in different research settings than highly developed economies (Mustikarini & Adhariani, 2022; Ye, 2023). Once with the adoption of various disruptive technologies in auditing practice, concerns about changes in the auditor-client negotiation process arise even more as they ensure higher data quality, data privacy, cybersecurity (Johri & Singh, 2024), and less impact of auditors' cognitive biases (Camilli et al., 2025; Lombardi et al., 2023), whereas some papers challenge their use from ethical perspective, cost considerations, or negative undetectable audit outcome generated by algorithm biases behind those technologies (Barr-Pulliam et al., 2024).

It is considered that specific negotiations occur between the client and the auditor until the audit contract is signed and after the actual mission is carried out. However, such relations between these two parties differ somewhat from general economic practice. This way, the auditors' negotiation approach affects both the audit process outcome (Gibbins et al., 2010; Salterio, 2012; Sanchez et al., 2007), and clients' auditor selection decision-making (Hanlon et al., 2022). Instead, auditors' choice for the negotiation strategies is strongly conditioned by both auditors' and clients' compatibility, or professional, social and personal traits (Lombardi et al., 2023; Trotman et al., 2011), seen from their dynamics along the audit negotiation process stages (Salterio, 2012). Those evolving dynamics on parties' interactions are significantly impacted by various factors, such as the quality of the auditor-client relationship, the power dynamics between dyads (e.g., negotiation style, negotiation experience, cognitive biases, historical accounting issues), clients' pressure, auditors' proficiency, corporate governance, or institutional environment.

Auditors and clients may also have various opinions on some aspects related to the valuation or estimate, but by the end of the audit engagement, both parties must reach a negotiated agreement. Literature reviews emphasized that the client's position can influence auditor opinion and vice versa. The literature emphasizes the relevance of integrative strategies based on the reciprocity approach between dyads (Agrawal et al., 2021; Perreault et al., 2017; Perreault & Kida, 2011) but outlines the use of distributive negotiation strategies as well (Hatfield et al., 2010). Nonetheless, studies emphasize the dynamic type of the auditor-client negotiation process related to financial statements quality, showing the relevance of the historical inputs and current changes in the context in which clients and auditors operate (Aghazadeh & Joe, 2022; Salterio, 2012).

Therefore, identifying the factors that influence the negotiation strategies used represent a valid concern nowadays, both from theoretical, regulatory and practical implications perspective. For this purpose, our study is aimed to provide answers to the research questions below:

RQ1: Which are the main factors that influence auditors' positioning during the negotiation process?

RQ2: What negotiation strategies and tactics do auditors prefer to employ in resolving disagreements with clients on accounting issues and their reporting severity?

The study argues that auditors' choice for different types of negotiation strategies is influenced by dyads' flexibility, the collaborative approach orientation of the negotiation, dyads' commitment to transparency and honest communication, or by the nature and duration of the auditor-client disagreements.

Our research adds to the literature fourfold. First, the study extends the literature addressing the topic of drivers of auditors' selection of negotiation strategy considering the research setting of an emerging economy, highly complex and driven by moderate institutional environment, respectively Romania. Second, we appreciate the results are partially generalizable, at least related to similar ex-communist eastern European economies, as the local regulatory set-up and public enforcement are significantly harmonized with regional setting, being a member of the EU. Third, the results could be used for public policy evaluation, standard-setting and oversight process purpose, to ensure minimum legal requirements and reasonable financial statements quality. Fourth, this paper is an invitation to academia and professional bodies to actively contribute to auditing practices by developing clear professional guidelines and standards to manage the auditor-client negotiation process effectively.

1 Theoretical background

An ongoing relationship between the auditor and its client represents the fundamental element of an efficient audit process. Maintaining a productive collaboration can only be achieved based on strategic and beneficial discussions for both parties involved. For this reason, specialized research tried to identify the factors that influence the negotiation process between auditor and client.

The theoretical background of the auditor-client negotiation research consists of various conceptual models. Scholars have considered various theories that emphasize the complexity of the topic, looking for multidisciplinary, interdisciplinary or even transdisciplinary research approaches, covering both economic, social and psychological research areas (Mustikarini & Adhariani, 2022; Ye, 2023).

The main theories relevant to the scope of this paper are the power-dependence theory, the agency theory, the institutional theory, the dual concern model and the ACN (auditor-client negotiation) dynamic theory.

The agency theory describes the role of monitoring activities performed by auditors to reduce the costs of agency incurred between shareholders and managers because of information asymmetry, which would justify a contending negotiation strategy if the auditor is independent of the client's audit fees (Beattie et al., 2015).

From the perspective of the institutional theory, auditors are influenced by several types of pressure when selecting the negotiation strategy. Coercive pressure emphasizes that auditors choose the negotiation strategies as per the minimum regulatory expectations set up by the institutional environment (MacTavish, 2018). Normative pressure forces auditors to commit to ethical professional standards and preserve their reputation on the market (Keller & Killough, 2009), which suggests auditors would prefer contending negotiation strategies to avoid or reduce the risk of noncompliance and litigation costs.

The dual concern theory emphasizes the role of the integrative negotiation strategies auditors should use, conditioned on the specific context of negotiation, in order to solve initial position disagreements and generate mutual benefits for dyads (Hatfield et al., 2010; Perreault & Kida, 2011).

Instead, Gibbins et al. (2001) propose a perspective of evolving dynamics of dyads interactions. This approach considers the process of negotiation as an iterative and dynamic process that shifts based on prior outcomes, ongoing expectations, and changing incentives (Salterio, 2012). For instance, in the initial negotiation stage, auditors prefer contending strategies and higher professional skepticism, whereas on the mid-term negotiations, they learn to adjust their expectations based on historical information which determine auditors to shift to compromising negotiation strategies.

The power-dependence theory underlines that auditors would choose a more contending negotiation strategy only as long as they base on strong regulatory backing, or higher reputation risk (Ye, 2023). The same theory is heightened through the lens of clients' initial advantage in negotiation and the role of their experience in negotiation and relationship with the auditor (Carlisle et al., 2023).

1.1 Drivers on auditors' choice of negotiation strategy

Negotiation research suggests several factors influencing auditor-client negotiation, including auditor-client relationship, client pressure,

auditor independence, auditor liability, clients level of scrutiny, auditors' and clients power of negotiation, frequency and severity of audit adjustments, corporate governance mechanisms, internal control systems effectiveness, dyads' cognitive biases, institutional framework, or other stakeholders influence (Knechel et al., 2013; Mustikarini & Adhariani, 2022; Simnett & Trotman, 2018; Trotman et al., 2011; Ye, 2023).

Hence, the nature and complexity of the auditor-client relationship considerably determine the negotiation direction in the audit (Agrawal et al., 2021; Gibbins et al., 2010; Perreault et al., 2017; Ye, 2023). Then, audit timing and negotiation of audit fees nevertheless interfere with the auditor-client negotiation process through the additional pressure clients exercise on auditors (Choudhary et al., 2022; Rothenberg, 2020), whereas audit findings (material misstatements) severity and frequency or waived audit adjustment (auditors' concessions) can lead to disagreements, affecting client retention rates (Hatfield et al., 2010; Hatfield et al., 2022; Joe et al., 2011; Perreault & Kida, 2011; Perreault et al., 2017; Vandennieuwenhuysen et al., 2023), along with the quality of financial statements (Choudhary et al., 2022; Knechel et al., 2013; Rennie et al., 2010; Simnett & Trotman, 2018; Trotman et al., 2011; Ye, 2023). However, better compatibility between auditors and clients determines auditors to increase their expectations concerning the quality of financial statements (Choudhary et al., 2022; Hatfield et al., 2022).

Besides those factors, the literature also underlines the role of auditors' and clients' characteristics (Abdollahi et al., 2024; Choudhary et al., 2022; Fuller et al., 2023; Mustikarini & Adhariani, 2022; Simnett & Trotman, 2018; Ye, 2023). Experience, professional background, credibility, integrity, and other similar characteristics of the parts involved in an audit process have a significant impact on the audit negotiation outcome. Instead, those characteristics are significantly conditioned by the local institutional environment and cultural factors (Camilli et al., 2025; Trotman et al., 2011; Vandennieuwenhuysen et al., 2023), especially when related to the auditors' selection process (Habib et al., 2019).

Further, we highlight the relevance of factors derived from auditor competencies in the audit negotiation process outcome that relate to role-playing (Trotman et al., 2005), auditor empowerment (Choudhary et al., 2022; McCracken et al., 2008), negotiation experience (Azmi & Voom, 2016; Fu et al., 2011; McCracken et al., 2008), auditors' behavior and auditors' judgment (Detzen & Gold, 2021; Trotman et al., 2011). Through role-playing, the auditor embraces the clients' position, manifests the situation from the opposite perspective, and communicates efficiently with the client, showing a high degree of concern and understanding. Auditor empowerment derives from the audit mission, as it empowers the auditor to conduct audit procedures, perform various analyses and tests, and recommend adjustments or changes in accounting treatments. An auditor's experience as a negotiator and audit judgement represents the hardcore for audit negotiation strategies.

Regarding going concern-related factors, financial risk measures are relevant in modeling the auditor-client negotiation. Auditors' reporting on going concern uncertainties signals capital markets, significantly affecting clients' medium- and long-term objectives, and increasing both firms' scrutiny and auditors' liability (Carson et al., 2013; Choudhary et al., 2022; Mustikarini & Adhariani, 2022; Rothenberg, 2020; Ye, 2023).

The set of resulting financial statements depends on the negotiation strategy used by the auditor (Agrawal et al., 2021; Brown et al., 2016; Dodgson et al., 2023; Hatfield & Mullis, 2015; Hatfield et al., 2010; Hatfield et al., 2022; Perreault & Kida, 2011; Perreault et al., 2017; Salterio, 2012; Sanchez et al., 2007). These strategies are put in practice by auditors using in the negotiation process various negotiation tactics, that could be used individually or in combination with others.

Related research has typically focused on determining the effect of the type of strategy selected by auditors in negotiating with the client, finding that:

- *Distributive (aggressive) strategies* – contending, compromising, conceding - appear when auditors make use of their expertise and experience to defend their initial position, including bringing additional arguments (Sabhay et al., 2019), especially in case of increasing cumulated differences between auditors and clients.
- *Integrative (conservative) – problem solving and value creation* - strategies support positive outcomes of the reconciliation process

for all the parties involved, like a mutual agreement between the two actors from the negotiation process.

The literature underlines the relevance of reciprocity-based negotiation strategies auditors can consider in the negotiation process with their clients due to the risk of diminishing client retention rates (Gibbins et al., 2010) or aiming for higher transparency exercised by clients' management (Perreault & Kida, 2011; Sanchez et al., 2007). Additionally, there are studies that highlight the effectiveness of the mix of negotiation strategies, which should be dynamic along the entire negotiation process, and conditioned by the emerging events of the selection context (Perreault et al., 2017; Rennie et al., 2010; Salterio, 2012).

Having said that, we formulate for testing purposes the following hypothesis:

H1: Going concern determines the auditor's choice towards contending negotiation strategies.

H2: Higher auditor liability induces auditors to prefer contending negotiation strategies.

H3: Client pressure leads auditors to choose contending negotiation strategies.

H4: Auditor independence determines auditors to adopt compromising negotiation strategies.

H5: Auditors' power of negotiation influences them to choose compromising negotiation strategies.

H6: The auditor-client relationship influences auditors' choice towards contending negotiation strategies.

H7: The choice of negotiation tactics has a significant influence on the auditors' final negotiation position.

Therefore, the reciprocity approach in the auditor-client negotiation research, together with considerations controlling for the evolution dynamics of dyads' interactions, is increasingly signaling the need of choosing

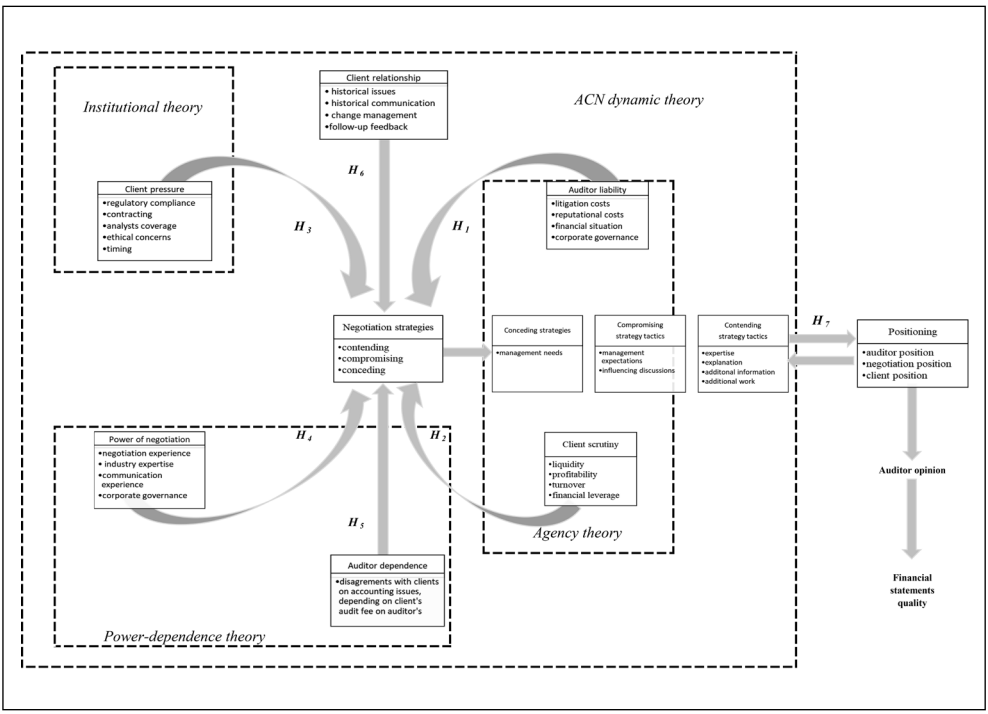

Fig. 1: Theoretical framework

Source: own

those negotiation tactics depending on the context and changes from the prior information known so far about the clients' processes, systems and human capital capabilities (Hatfield et al., 2010; Perreault et al., 2017). However, we have not captured in this paper the topic of either the mix of negotiation strategies or the mix of negotiation tactics aimed to use different framing and manipulation techniques.

Theoretical framework and the hypotheses are described further in Fig. 1.

2 Research methodology

2.1 Data collection and demographics

The study addresses the relevance of different factors on auditors' position during the negotiation process with audit clients. The population considered for our research is represented by the active auditors, members of CFAR (Chamber of Financial Auditors from Romania), covering the entire geographical areas, with focus on the counties reporting the highest economic development.

The population was built with support from CFAR, considering both audit firms and financial auditors working independently. As a final filter, we have considered only the auditors that have reported at least one mission during 2021 to CFAR in our population. For this purpose, we have designed a questionnaire similar to studies that address the same topic we do, such as Gibbins et al. (2010). The questionnaire consisted of 52 items (excluding items describing auditors' profiles) valid for our research, disseminated through the Google Form platform. The items are represented by closed questions, using Likert scale from "1" reflecting complete disagreement, and "5" describing complete agreement. Additional to these items, 3 items are considered to reflect auditors' perception of three dimensions of results of negotiation, respectively: auditors' position, clients' position and negotiated position.

The period of dissemination is between July 1, 2022 and July 31, 2022. The invitation to fill in the questionnaire was distributed with the support of CFAR through the institutional email of the professional organization. In total, 232 invitations were distributed by email. We received 101 valid filled-in questionnaires, meaning approximately 43.53% rate of response.

In Fig. 2, we summarize the main characteristics of the auditors' socio-demographic profile. Overall, the charts show most of the respondents are at least audit directors (64.36%), which is expected in our results to reflect a strategic

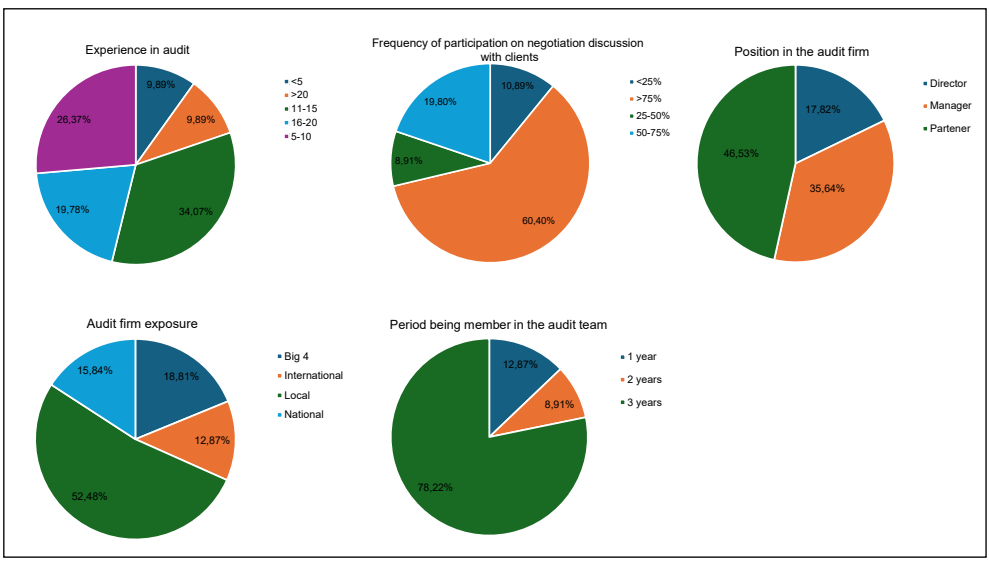

Fig. 2: Sample socio-demographic characteristics

Source: own

view on the topic we address in the study. Respondents' experience in audit shows a high experience of at least 11 years (63.74%). Instead, the exposure to the international business landscape seems to be lower (31.68%).

These demographic characteristics suggest the results reflect predominantly a national perspective. However, the high experience of respondents and their position in the audit firms reflect better the background of the negotiation discussions and lead us to expectations of higher conservatism on auditors' positioning during negotiations with clients. Instead, the lower rate of rotation of members of the audit team participating in negotiation discussions gives an indication of a stronger relationship with the clients and a higher power of negotiation.

2.2 Data reduction

As our sample consists of a high number of questions and as many of them relate to similar core concepts addressed within our research design, such as a power of negotiation, clients' pressure, audit risk, or negotiation strategies, we had to reduce the data collected to ensure simplicity and clarity for the econometric model that is later estimated. In Fig. 3, we describe the conceptual framework considered for data reduction.

For this purpose, we proceed with categorical principal components analysis (CatPCA), which is specially designed for categorical data collected through questionnaires (Meulman et al., 2004). The method consists of optimal scaling of categorical data by assigning optimal scale values to each of the categories, in order that, for a specified number of dimensions, the overall variance accounted for the transformed variables is maximized.

The method of CatPCA is performed considering a rotated solution, obtained through the Varimax rotation procedure. After simulation of CatPCA solutions for different number of dimensions, we remain to the solution that maximizes the variance factors accounted for in the sample, but with a minimum number of factors, so that we reduce the risk of components overlapping (Hair et al. 2019). The procedure is performed separately for both periods analyzed in this study.

2.3 Ordinal regression analysis

Once estimated the scores for each construct, we proceed to an econometric analysis to assess their marginal effect on consumers' decision concerning the value per ecommerce transaction and on consumers' opinions regarding the likelihood to perform in the future as well ecommerce transactions. For this purpose, we estimate a generalized ordinal regression model, as the dependent variable indicates clear order between the different possible values. The dependent variable in case of each model estimated is an ordinal type variable that can take five different levels, depending on the levels of Likert scale used to measure auditors' perception of the relevance of various factors expected to influence the output of discussions concerning the negotiation of the final form of the audit report.

In each of the estimated models, we consider the minimum value possible as a reference. In general, in case of k possible values for the dependent variable, we estimate $k - 1$ binary regression models expressed by the relation below:

$$\begin{aligned}\ln \frac{P(y_i = j)}{P(y_i = r)} &= \beta_0 + \beta_1 \cdot Client\ scrutiny_i + \\ &+ \beta_2 \cdot Auditor\ liability_i + \beta_3 \cdot Ethical\ issues_i + \\ &+ \beta_4 \cdot Comercials\ contracting_i + \\ &+ \beta_5 \cdot Auditor\ proficiency_i + \\ &+ \beta_6 \cdot Client\ corporate\ governance_i + \\ &+ \beta_7 \cdot Auditor\text{-}client\ relationship_i + \\ &+ \beta_8 \cdot Auditor\ dependence_i + \\ &+ \beta_9 \cdot Conservative\ strategies_i + \\ &+ \beta_{10} \cdot Agressive\ strategies_i + \varepsilon_i\end{aligned} \quad (1)$$

where: β – the vector of regression coefficients; $P(y_i = j)$ – the probability that outcome j is selected; r – the "pivot" (reference) outcome; x_i – the vector of independent variables considered for each respondent included in our sample, including the constructs determined based on CATPCA procedure and variables describing respondents' profile relevant characteristics for the analysis.

$$\ln \frac{P(y_i = j)}{P(y_i = r)} = \frac{e^{\beta_j \cdot x_i}}{1 + \sum_t^{k-1} e^{\beta_j \cdot x_i}} \quad (2)$$

Based on this odds ratio, we determine the probability that an individual changes his preference, from the r outcome to the new j preference, based on Equation (1).

Therefore, as per Fig. 1, we emphasize the link between the dimensions from

Equation (1) and the research hypotheses, with reference to the theoretical framework basis that allowed us to describe the expected association between auditor negotiation strategy outcome related factors.

Additional tests of robustness are performed to strengthen the initial results. For this purpose, we have considered a distinct grouping of the responses based on several criteria supported by the literature. First, we have looked at identifying any notable differences in the negotiation outcome related to Big 4 firms, compared with the whole sample, as Big 4 firms are perceived to have power of negotiation in relation to their clients (in relation to the standard-setters as well), and wider knowledge and extensive technical resources to support their positions (Brown & Knechel, 2016; Vandennieuwenhuysen et al., 2023), whereas non-Big 4 companies would rely more on consolidating a long-term relationship with the clients and arguments in most instances with reference to the best practice in the industry. Second, we check for any differences determined by the audit tenure factor to understand better a compensating measure of the auditor-client relationship, as longer audit tenure is expected to align both the auditor and client expectations concerning the process of financial reporting and its outcome (Abdollahi et al., 2024; Svanberg et al., 2018). Last but not least, we look for any significant gaps in factors reviewed so far in the paper, but this time from the lens of potential effects of the power dynamic on higher level versus lower level of decision-making, as the literature outlines that clients' management has different negotiation approaches when discussing with the staff-auditor, the audit managers, or the audit firm partners (Carlisle et al., 2023).

3 Results and discussion

3.1 Factors influencing auditors' position

Tab. 1 summarizes the main descriptive statistics on item-level analysis for items included in the questionnaire disseminated for our research.

Financial auditors' perception of using different negotiation strategies during the reconciliation discussions with the client highlights a more auditor position-oriented process. They expressed a high level of perception of the need to adopt strategies such as: bringing more explanations to the clients to emphasize their findings, using their expertise to influence the final resolution on the auditors' conclusions, or even being willing to perform additional procedures and testing to find out more conclusive evidence to get client's management acceptance of the initial findings.

It is interesting, but still not surprising, that the perceptions auditors have expressed are related to the relevance of the information that indicates the client's financial stability premises. We witnessed the recent COVID-19 pandemic, which again shows the economic world that uncertainty circles around the current construction of the economic systems, including the Romanian one. From this perspective, auditors have learned from the previous financial crisis and the more recent COVID-19 pandemic has influenced how important the premise of a client's going is when making decisions on accepting an audit mission, establishing the volume of work, or having discussions of reconciliation with the clients.

Similar relatively high importance has been given to essential aspects concerning the client, with impact on the overall level of risk of audit, as nowadays the level of trust has become fundamental on the equation of each contractual relation, especially when addressing the potential litigation costs that might be incurred by low quality (even unintended) of audit work, or when searching for client's management team reputation historical information.

Financial auditors' have emphasized quite clearly how important their independence and objectivity are in having a final resolution concerning audit findings identified during the audit mission. The relatively low level of items addressing different factors of auditors' potential bias on their opinion, such as the perspective of contract extension, the negative effects on audit fees, or even the conflicting discussions between auditors and clients concerning noncompliance with legal requirements other than concerning the financial audit mission and the financial reporting regulation, proves that auditors defend their professional independence., no matter the financial impact will be on their revenues (Salterio, 2012).

The same straight position auditors have concerns about their independence, including the negative financial effects resulting from the relationship with the client. Auditors expressed a low level of perception of their opinion of how much adjustments on audit findings

during reconciliation meetings are conditioned by their revenue dependence on clients' contracting premises.

Auditors show they are highly focused on the financial reporting aspect of the audit mission and less on other clients' operations aspects, including analysts' forecasts. However, the high level of perception expressed by auditors when addressing the problem of contracting non-audit services with the same clients is interesting, and raises awareness of their independence.

The role of effective corporate governance mechanisms proves to be highly relevant from auditors' perception (4.089), as well as the role of the effectiveness of internal controls. Auditors seem to be aware of the need for a formal communication framework with the client that conserves their level of independence and reduces the risk of audit significantly (Mustikarini & Adhariani, 2022).

The rather conflicting position expressed by auditors during reconciliation meetings also seems to be confirmed by the confidence in their experience in auditing, their expertise in the clients' industry specifics, and their communication skills.

3.2 Dimensional analysis on factors reviewed

The set of items included in the questionnaire disseminated among the active CAFR financial auditors are reduced to several dimensions, to provide us a more concise image of the relevant key aspects considered by auditors' when making decisions related to audit adjustments during reconciliations discussions with clients audited.

In Tab. 2, we summarize the basic statistics of the categorical principal components analysis (CatPCA). The results of the CatPCA analysis emphasize ten constructs that reduce the data obtained through the questionnaire dissemination. All the constructs extracted seem to be representative of the reduced data, as the dimensions cover more than 65% of the total variation in most of the constructs (Hair et al. 2019).

The first level of grouping items incorporates information about auditors' perception of the usefulness of various negotiation tactics used by auditors during reconciliation meetings with clients for possible audit findings adjustments. Two dimensions were extracted, making a separation between the items that reflect

Tab. 1: Survey item-based descriptive statistics – Part 1

Item	Variable	Item description	Mean	Std. dev.
How frequently did you use the following negotiation strategies?				
4	*Information*	Additional information on discussion	2.931	1.267
5	*Expectations*	Try to meet management expectations	2.228	1.028
6	*Explanations*	More arguments to support auditor's position	4.525	0.832
7	*Middle*	Try to find a compromise solution	3.158	1.129
8	*Influence*	Auditor influences management for acceptance	2.584	1.211
9	*Expertise*	Auditor expertise used to influence management	4.287	0.852
10	*Work*	Additional work to get management acceptance	3.812	1.138
11	*Needs*	Try to meet management needs	2.198	1.020
12	*Concession*	Make concessions to get management acceptance	2.188	1.111
How relevant do you consider the following factors for risk assessment?				
13	*Liquidity*	The level of liquidity	3.891	1.067
14	*Profitability*	The level of profitability	3.782	1.055
15	*Activity*	The level of activity	3.911	1.050
16	*Statements*	Relevance and accuracy of financial statements	4.168	0.917

Tab. 1: Survey item-based descriptive statistics – Part 2

Item	Variable	Item description	Mean	Std. dev.
To what extent do you consider the following factors relevant when deciding on adjustments to audit findings?				
17	*Litigation*	Litigation costs related to audit missions	3.802	1.463
19	*Reputation*	The business reputation of client's management	3.604	1.225
20	*Stability*	Stability in client's financial position	3.495	1.205
How much do you consider the following traits to decide on adjustments on audit findings?				
23	*Prolongation*	The contract could not be extended	2.644	1.553
24	*Audit fees*	The audit fees will be negatively affected	2.594	1.498
25	*Compliance*	Divergences with clients related to various aspects	3.337	1.177
26	*Forecasts*	Analysts' forecasts	3.020	1.216
28	*Deontology*	Noncompliance with other legal requirements	2.188	1.247
29	*Ethical*	Breach of profession ethical code	3.366	1.347
27	*Non-audit*	Contracts with clients for non-audit services	4.317	1.113
31	*Contract*	It is clear the contract is not extended anymore	2.277	1.386
How often have you adjusted contracts during revenue recognition?				
34	*Insignificant*	0–10%	2.941	1.448
35	*Low*	11–25%	3.030	1.330
36	*Moderate*	25–50%	3.030	1.431
37	*Significant*	50–75%	3.109	1.476
38	*Essential*	75–100%	2.822	1.602
How relevant do you consider the following factors when deciding on adjustments to audit findings?				
34	*Experience*	Experience in audit	4.238	0.896
35	*Specialization*	Expertise in the industry the client runs its operations	4.069	0.951
36	*Presentation*	Experience in communication and training	4.101	0.995
21	*Quality*	Assess the quality of the audit activity	1.455	0.878
37	*Internal controls*	The existence of internal controls	3.762	0.950
38	*Governance*	The existence of corporate governance mechanisms	4.089	0.896
39	*Committee*	The support provided by the audit committee	2.743	1.426
How much do you consider the following factors in the decision to adjust the audit findings?				
34	*Feedback*	Experience in cooperation with the client	4.129	0.966
35	*Communication*	The level of communication with the client	4.208	0.993
36	*Period*	The period of business relationship with the client	4.020	1.020
37	*Change*	Changes in the level of top management	3.891	1.207
38	*Follow-up*	Solutions to previous audit findings from the client side	4.040	1.076

Note: The table provides the items selected from the questionnaire, which show significant variance among respondents. The items are grouped based on categories highlighted by literature, such as: types of negotiation strategies, clients' financial risk assessment, audit engagement risk assessment, client pressure, auditors' client's portfolio structural dependence, power of negotiation defined as per the dimensions of auditors' expertise and clients' corporate governance, and client relationship maturity.

Source: own

better, more contending strategies selected by auditors on the negotiation with the clients (aggressive strategies), and respectively, strategies that auditors choose rather than when they are willing to come to an agreement with the clients concerning accounting issues identified on preparing the financial statements (conservative strategies).

On the one hand, the construct of aggressive strategies shows that auditors prefer to make use of their expertise and experience to defend their initial position, including bringing additional arguments to clients' managers to clarify the essence of the audit finding, in spite of CFOs/ Audit Committees' position of disagreement. This dimension explains approximately 42.69% of the total variation on the level of this set of items included in the questionnaire.

On the other hand, the construct of conservative strategies incorporates all the items that describe negotiation tactics aimed to reach a consensus between auditors and clients, both winning. This dimension explains approximately 16.72% of the total variation on the level of this

Tab. 2: Constructs descriptive statistics – Part 1

	Item	Reliability analysis			Categorical factor analysis				
		Cronbach's alpha	*F*	Sig.	Construct	Eigenvalue	% of variance	Vector coordinate	Loadings
Negotiation strategies	4	0.785	102.30	0.000	*Conservative strategies*	3.842	42.69	0.485	0.697
	5							0.790	0.889
	7							0.422	0.650
	8							0.267	0.516
	10							0.340	0.583
	11							0.724	0.851
	12							0.725	0.851
	6				*Aggressive strategies*	1.505	16.72	0.690	0.831
	9							0.595	0.772
Financial risk profile	13	0.809	5.31	0.001	*Client scrutiny*	2.796	69.89	0.741	0.861
	14							0.636	0.798
	15							0.720	0.848
	16							0.698	0.836
Audit risk	17	0.776	10.35	0.000	*Audit liability*	2.511	62.77	0.533	0.730
	18							0.682	0.826
	19							0.816	0.903
	20							0.479	0.692
Client pressure	23	0.936	32.93	0.000	*Noncompliance client*	3.751	46.88	0.586	0.766
	24							0.652	0.808
	25							0.575	0.759
	26							0.642	0.801
	28							0.547	0.739
	29							0.352	0.593
	27				*Contract client*	1.783	22.28	0.557	0.746
	31							0.432	0.657

Tab. 2: Constructs descriptive statistics – Part 2

	Item	Reliability analysis			Categorical factor analysis				
		Cronbach's alpha	*F*	Sig.	Construct	Eigenvalue	% of variance	Vector coordinate	Loadings
Auditor dependence	34	0.789	46.31	0.000	*Auditor dependence*	3.438	68.77	0.571	0.756
	35							0.567	0.753
	36							0.789	0.888
	37							0.771	0.878
	38							0.741	0.861
Power of negotiation	34	0.709	103.20	0.000	*Auditor proficiency*	3.434	75.22	0.918	0.958
	35							0.858	0.926
	36							0.744	0.863
	21							0.489	0.699
	37				*Governance client*	2.024	52.60	0.611	0.782
	38							0.583	0.763
	39							0.385	0.620
Client relationship	34	0.902	3.67	0.006	*Client relationship*	3.832	76.64	0.821	0.906
	35							0.789	0.888
	36							0.854	0.924
	37							0.733	0.856
	38							0.635	0.797

Note: The table provides the results of data reduction considering all the 51 items (except for the auditors' profile) incorporated into the questionnaire used in the analysis. The data reduction is performed using the categorical principal components analysis (CatPCA). Cronbach's alpha higher than 0.700 shows the reliability of the scale (Hair et al., 2019). The eigenvalue statistics indicate that each dimension identified contributes at least 10% to the total variation across respondents' expressed perception of drivers of auditors' choice for different negotiation strategies. The loading statistic of at least 0.600 suggests the dimensions identified are representative for the items behind them (Hair et al., 2019).

Source: own

set of items included in the questionnaire. Looking at the loading of the items included in this construct, we observe that it is highly influenced, especially by tactics such as meeting management expectations or conceding in change of other clients' concessions, for accounting issues that are insignificantly material.

The dimension of *financial risk* incorporates the items from the questionnaire that describe the client's financial risk profile from the perspective of the client's liquidity, profitability, or relevance of the financial statements. This construct is essential to the auditors' efforts to assess clients' going concern premises, with significant implications for evaluating their assets, debts, and capital. This dimension explains approximately 69.89% of the total variation on the level of this set of items included in the questionnaire.

The *audit risk* construct incorporates the items addressing aspects of the audit risk of each audit mission, respectively the level of perceived litigation costs related to each audit mission, the business reputation of clients' management and the indications of clients' financial stability. This dimension proves to be essential for the auditors' decision-making reasoning, influencing aspects such as the acceptance of an audit engagement and the extent of audit activities carried out during the engagement. At the same time, the auditor's competitive positioning in reconciliation discussions with

clients is significantly influenced and possibly conditioned by this dimension of risk. From a statistical perspective, this dimension accounts for approximately 62.77% of the total variance of the items included in the questionnaire, highlighting its analytical relevance.

Auditors' level of independence and objectivity represent core requirements for ensuring audit quality and reducing auditor's liability and potential reputational costs. However, the relationship between auditors and clients endangers those requirements, especially in case of long relationships and significant weaknesses on auditors' capabilities and expertise in the areas of auditing, financial reporting and clients' business model particularities. Therefore, clients put pressure on auditors to reduce the magnitude of audit adjustments during reconciliation discussions. This dimension is explained in this study by two constructs, respectively the *noncompliance client* construct and the *contract client* construct.

The construct of *noncompliance client* aggregates auditors' perception of the importance given to disagreements on legal requirements of accounting treatments or on following the professional and business code of conduct. This dimension explains approximately 46.88% of the total variation on the level of this set of items included in the questionnaire.

The construct of *contract client* reduces information related to only two items of the questionnaire. On the one hand, the construct relates to the information about the existence of non-audit services with the clients. On the other hand, the construct refers to auditors' perception of the certainty of the fact that the audit contractual relationship with the client will cease. This dimension explains approximately 22.28% of the total variation on the level of this set of items included in the questionnaire.

The construct of *auditor dependence* reflects auditors' perception of how much they perceive the contractual relationship with the client will affect their future revenues. In case of audit firms with revenues invoiced to only a few audit clients, their financial perspectives are sensitive to the outcome of the discussions of reconciliation with the audit clients ensuring a major part of the revenue. In those circumstances, the auditors' independence could be drastically affected. This dimension explains approximately 68.77% of the total variation on the level of this set of items included in the questionnaire.

Auditors' power of negotiation is a sensitive element when modelling the premises, the factors and the outcome of the reconciliation discussions between the auditor and the client. Despite the legal requirements setting up several key aspects of clients' management decisions concerning the change of the auditor (Rothenberg, 2020), the auditor tenure, or the auditor rotation, the negotiation power of audit firms is significantly affected by clients' management position during the reconciliation discussions, with implications on audit quality (DeFond & Zhang, 2014; Knechel et al., 2013). This dimension is resumed to two constructs, respectively, the *auditor proficiency* construct and the *governance client* construct.

The *auditor proficiency* construct relates to auditors' perception of the role of auditing and negotiation (communication, including presentation skills) as well, whereas the industry-specific knowledge represents another core pillar of defining the level of auditors' competencies and abilities. This dimension explains approximately 75.22% of the total variation on the level of this set of items included in the questionnaire.

The *governance client* construct incorporates auditors' perception of the relevance of corporate governance mechanisms, internal controls effectiveness, and support from audit committees. This dimension explains approximately 52.60% of the total variation on the level of this set of items included in the questionnaire.

The last dimension considered in our analysis is the *client relationship* construct, which incorporates the items addressing aspects of the relationship between the auditor and the client, such as the long-term cooperation of the auditor with the client, the proactive communication style of both the auditor and the client, the audit tenure, or clients' efforts to implement audit recommendations from previous audit reports This dimension explains approximately 76.64% of the total variation on the level of this set of items included in the questionnaire.

3.3 Discussion on the identified dimensions

The marginal effects of each construct identified by the CatPCA are analyzed by estimating ordinal regressions. The results of the models estimated per each reconciliation meeting position addressed in the questionnaire are summarized in Tab. 3.

Tab. 3: Ordinal regression analysis

Factors identified	Dependent variable								
	Auditor position	*Negotiated position*	*Client position*	*Auditor position*	*Negotiated position*	*Client position*	*Auditor position*	*Negotiated position*	*Client position*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Financial risk client	0.132	0.244	0.286**	–	–	–	0.205	0.205	0.238**
	(0.142)	(0.138)	(0.139)				(0.146)	(0.140)	(0.141)
Audit risk	−0.042	0.099	−0.020	–	–	–	0.069	−0.012	−0.176
	(0.138)	(0.131)	(0.132)				(0.151)	(0.143)	(0.144)
Noncompliance client	−0.503*	0.049	−0.206	–	–	–	−0.500*	0.007	−0.278
	(0.172)	(0.161)	(0.165)				(0.175)	(0.164)	(0.168)
Contract client	0.515*	−0.049	0.359*	–	–	–	0.505*	−0.027	0.403*
	(0.135)	(0.118)	(0.123)				(0.135)	(0.119)	(0.126)
Auditor proficiency	0.041	0.044	0.033	–	–	–	−0.070	0.129	0.144
	(0.133)	(0.130)	(0.132)				(0.141)	(0.137)	(0.139)
Governance client	0.157	0.138	0.128	–	–	–	0.194	0.108	0.084
	(0.124)	(0.121)	(0.121)				(0.127)	(0.123)	(0.122)
Client relationship	0.302*	0.058	0.095	–	–	–	0.251	0.091	0.134
	(0.158)	(0.152)	(0.151)				(0.160)	(0.154)	(0.154)
Auditor dependence	−0.004	0.003	−0.179	–	–	–	0.023	−0.031	−0.242
	(0.149)	(0.143)	(0.145)				(0.154)	(0.145)	(0.148)
Conservative strategy	–	–	–	−0.299*	0.334*	0.086	−0.247	0.266**	0.381*
				(0.112)	(0.108)	(0.105)	(0.149)	(0.142)	(0.145)
Aggressive strategy	–	–	–	0.239**	−0.040	−0.049	0.243**	−0.106	−0.096
				(0.107)	(0.104)	(0.104)	(0.116)	(0.111)	(0.113)
Model validation									
Pseudo R^2	0.131	0.053	0.082	0.043	0.033	0.003	0.157	0.068	0.108
LR statistic	35.790	15.630	24.700	11.780	9.733	0.891	42.900	20.080	32.450
Prob.	0.000	0.048	0.002	0.003	0.008	0.641	0.000	0.029	0.000
AIC	2.590	3.002	2.975	2.709	2.942	3.092	2.559	2.998	2.938

Note: The table provides estimates of ordinal regression models, considering the different auditors' orientations when deciding on how to conclude on the audit adjustments identified and debated during the reconciliation meetings with their clients' management. The dependent variables represent the outcome of the CatPCA procedure performed prior to reducing data on each of the groups of items incorporated in the questionnaire administered to the auditors. The three orientation auditors were asked to place within the definition of distributive negotiation strategies as per Gibbins et al. (2010). The related negotiation tactics are captured by the *conservative strategy* and *aggressive strategy* constructs. * 0.01 significance level; ** 0.05 significance level.

Source: own

As per Hatfield et al. (2010), auditors are tempted on their initial position to choose rather a contending strategy than a compromising one, including related negotiation tactics, such as using his/her influence on the negotiation, pointing out the requirements from the industry, or eventually threatening the client with an unqualified opinion. Based on our results, auditors' aggressive position is determined both by *client pressure* and *client relationship* constructs.

First and surprisingly, the *noncompliance client* construct negatively affects the probability auditors would commit to their initial position in the negotiation along all econometric model estimates (e.g., Model 1: β = −0.503, Sig. = 0.003). Therefore, disagreement between auditors and clients on accounting issues (divergent interpretations) or legal requirements issues represent an area where the auditors seem to be open to negotiating, as both auditors and clients' management are aware that in case of complex issues, collaboration to identify a solution is essential, including relying on clients' expertise (Agrawal et al., 2021; Hux, 2017; Messier & Schmidt, 2018). One important item incorporated in this construct is related to auditors' awareness of analyst's forecast, which suggests that an analyst's coverage is perceived positively by auditors, but could lead to significant judgement bias on his/her resolution (Camilli et al., 2025; Lombardi et al., 2023). However, in case of recurrent, historically waived adjustments not remediated from one period to another, auditors are placed at high risk. In those circumstances, the auditors are in the position to practice higher skepticism to ensure minimum regulation requirements are followed and some internal materiality thresholds are not exceeded (Hatfield et al., 2022; Messier & Schmidt, 2018). However, there is evidence in the literature that confirms the treatment of waived audit adjustments is linked to the maturity of auditor-clients relationship, clients' pressure on auditors, exercised by increasing audit hours for the next audit engagement (Choudhary et al., 2022), or auditors' early involvement on deciding the treatment on the related accounting issue identified (Hatfield et al., 2022; Perreault & Kida, 2011).

Instead, another dimension of client pressure relates to the contractual commercial agreement with the client, which is represented by the *contract client* construct. This construct positively influences the probability that the auditor would insist during negotiations on the initial position (e.g., Model 1: β = −0.515, Sig. = 0.001). This instance suggests that auditors become more aggressive in the negotiation in case of providing additional non-audit services, which could lead to suspicions about the auditor's subjectivity (Schneider et al., 2006). The fact that this construct has the highest negative marginal effect on auditors' contending position in negotiations with the client suggests that auditors' independence could be slightly affected. These results are in line with the findings from Rennie et al. (2010) or Schneider et al. (2006) on auditor independence. Instead, they contradict previous research, such as Choudhary et al. (2022) from the perspective of auditor skepticism and trust levels. Additionally, auditors appear to be more contending in their negotiation approach when they already know they will not get for the next year the contract of assurance services, issuing more concerns on the quality of the financial statements, including via the critical (key) audit matters disclosure (Aier et al., 2024). Our results somehow contradict Das et al. (2025), showing auditors' professional judgement is significantly affected in firms incentivizing auditors based on performance-based profit-sharing schemes. This remuneration scheme, in conjunction with clients' pressure that push for waiving or eliminating different audit adjustments, would affect the auditors' judgement before the negotiation process starts. However, as our research design did not control for the auditors' (partners) bonus scheme, this appreciation would be inconclusive. Therefore, *H3* can be confirmed.

Additionally, the results confirm a positive statistical impact of the *client relationship* construct on the probability that auditors would position the negotiation more aggressively, as reflected in Model 1 (β =0.302, Sig. = 0.005). As per the dynamic auditor-client negotiation theory, along the time of auditor tenure, compatibility between auditors and clients increases, leading each negotiation party to understand better the other side's expectations (Brown & Knechel, 2016; Fuller et al., 2023; Svanberg et al., 2018). There are studies that even emphasize the current practice of audit firms assigning relationship partners, in charge to ensure a smoother negotiation process between the auditor and the client that seem to be effective (Dodgson et al., 2021). Instead, if clients' management observes auditors' deviation from those expectations determined based on the historical auditor-client relationship, they offer less concession (Dodgson et al., 2023). Nonetheless, auditors get a better understanding of clients' processes, systems, human capital and other corporate capabilities relevant to ensuring reasonable financial reporting quality (Abdollahi et al., 2024; Fuller et al., 2023).

The significance of this construct is in line with the literature which states clearly that the auditor-relationship management dimension represents an essential element of the context they relate to when choosing a negotiation strategy and its related tactics, especially in case of auditors' choosing a more integrative negotiation strategy (Gibbins et al., 2007; Hatfield & Mullis, 2015; Hatfield et al., 2022; Mustikarini & Adhariani, 2022; Svanberg et al., 2018). This relationship is analyzed many times in the literature through the lens of power dynamics between auditors and clients' management, which change along different negotiation process stages (Hatfield et al., 2010; Salterio, 2012). Instead, scholars raise the risk awareness of a lack of balance between the two parties. On the one hand, more contending clients' management, which generally fights from a higher position of power in the initial negotiation process (Carlisle et al., 2023), can deceive auditors through different framing techniques (Aghazadeh & Joe, 2022) or timing concession strategy (Aghazadeh et al., 2020), and in conjunction with client pressure on commercial aspects of the contractual relation with the auditor, can hide or at least convince auditors to waive material audit adjustments (Azmi & Voom, 2016; Choudhary et al., 2022; Joe et al., 2011). On the other hand, auditors have sufficient leverage to convince clients on their audit adjustments to be operated on the released form of the financial statements, as clients' management position is rather explained by other organizational (e.g., prospect for an IPO) or personal objective (e.g., bonus schemes) (Brown et al., 2016; Fu et al., 2011). The only question mark here is the timing of the alignment between auditors' objectives and clients' management objectives, which generally negatively affects the severity of proposed audit adjustments in the short term (Aghazadeh et al., 2020; Gibbins et al., 2010), but positively on a multi-period setting (Cheng et al., 2017). The longer the time, the higher is expected to be the negative impact on the clients' side, as they did not concede at the right moment, mainly because of insufficient experience in negotiation and wrong appreciation of auditors' expectations (Agrawal et al., 2021). However, this leverage, the auditors have is limited by clients' choice of the future auditor or the number of hours of audit invoiced (Carlisle et al., 2023; Choudhary et al., 2022; Messier & Schmidt, 2018). In that circumstance, auditors' position becomes even more rigid under the auspicious of public oversight mechanisms, such as audit firms' inspections and penalization (MacTavish, 2018). Instead, audit firms decide on this dilemma based on cost-benefit analysis, as auditors are willing to assume deficiency exposure as long as the audit fees compensate for this risk, especially in case of clients under lower scrutiny conditions (Acito et al., 2018). With those results, we can confirm *H5*.

The *auditor proficiency* construct does not significantly impact the auditors' position in the final stage of the negotiation process (e.g., Model 1: β =0.041, Sig. = 0.761), which would be in line with Azmi and Voom (2016), which shows some clients' negotiation strategies (e.g., timing concession strategy related tactics) can deter audit adjustments severity, no matter auditors' experience or expertise on the industry the clients' operate in, when auditors are constrained by contracting concerns, or they do not use effective negotiation tactics to combat clients' strategies. Instead, our results show that auditors' choice of different negotiation tactics influences the final result of the negotiation significantly, showing a positive impact on auditors' orientation towards the more contending approach to the negotiation (e.g., Model 7: β =0.243, Sig. = 0.036), whereas a favorable impact is observed on auditors' preference for a rather more compromising negotiation strategy (e.g., Model 8: β =0.266, Sig. = 0.062). These results provide an indication that auditors' contending position in the negotiation with the clients is mainly affected by their choice for more aggressive negotiation strategies, either they are sequentially used on different phases of discussion, or if they synchronize those strategies at once. Aggressive strategies appear when auditors make use of their expertise and experience on defending their initial position, including bringing additional arguments, extending the discussion agenda, or performing additional tests (Sabhay et al., 2019). The results (either the aggressive strategy, or the conservative strategy constructs are statistically significant in Model 7 and Model 8), show that auditors prefer to approach the negotiation process considering distributive strategies, with preference for either contending negotiation tactics, or compromising negotiation tactics. Our results are somehow explainable from the perspective

of a weaker institutional environment, which shows only a moderate index of judicial system effectiveness, which would lower auditors' premises to use as an argument for the need that clients follow the minimum regulatory requirements (Boyle, 2024). The context provided by the regulation is highly synergic with investors' perception of the capital markets as well, as the change of the auditor represents sensitive information for them, providing an indication of potential material issues a firm audited would like to hide (Habib et al. 2019). Therefore, it is not only the auditor who has to provide audit quality, but also the client is expected to ask for audit quality, with significant benefits when such orientation is decided voluntary, not determined by regulation similar to SOX requirements (DeFond & Zhang, 2014). The only problem that seems to persist over time is related to the audit expectations gap, which clearly cannot be solved only via standard-setting, but an increase in shareholders and stakeholders awareness of what should be the expectations from an auditor (Quick, 2020), including what capabilities they should prove on different local and industry-specific dynamic context (Deepal & Jayamaha, 2022). These findings provide empirical support for the validation of hypotheses *H6* and *H7*.

3.4 Robustness results

In Tab. 4, we provide estimation results of additional ordinal regression models for robustness purposes. Overall, the results are similar to those presented in Tab. 3.

First, results confirm a significant impact of the *auditor proficiency* construct on the more conservative (aggressive) auditor position (Model 12: β =1.215, Sig. = 0.013) in case of one model estimated, which indicates audit partners pay attention to the relevance of the audit firm's experience, expertise on the field (especially

Tab. 4: Ordinal regression analysis – Part 1

Factors identified	Dependent variable (group analyzed)								
	Auditor position			*Negotiator position*			*Client position*		
	Non Big 4	Auditor tenure	Partner	Non Big 4	Auditor tenure	Partner	Non Big 4	Auditor tenure	Partner
	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Financial risk client	0.153	0.124	−0.235	0.200	0.389**	0.369**	0.259**	0.373**	0.370**
	(0.147)	(0.173)	(0.222)	(0.142)	(0.166)	(0.214)	(0.143)	(0.166)	(0.214)
Audit risk	−0.077	−0.120	0.204	0.121	−0.002	0.258	−0.024	−0.150	0.140
	(0.143)	(0.156)	(0.210)	(0.137)	(0.146)	(0.207)	(0.137)	(0.147)	(0.204)
Noncompliance client	−0.524*	−0.833*	−0.675*	−0.027	0.139	0.186	−0.248	−0.044	−0.378
	(0.196)	(0.216)	(0.269)	(0.181)	(0.190)	(0.251)	(0.186)	(0.193)	(0.255)
Contract client	0.459*	0.549*	0.741*	−0.027	−0.134	−0.085	0.351*	0.308**	0.403**
	(0.145)	(0.149)	(0.194)	(0.130)	(0.131)	(0.161)	(0.135)	(0.136)	(0.170)
Auditor proficiency	0.016	−0.069	1.215**	0.083	0.002	−0.082	0.070	0.045	0.206
	(0.139)	(0.148)	(0.492)	(0.135)	(0.142)	(0.442)	(0.136)	(0.146)	(0.493)
Governance client	0.191	0.255	−0.282	0.159	0.171	0.021	0.139	0.167	−0.113
	(0.139)	(0.182)	(0.254)	(0.134)	(0.175)	(0.245)	(0.133)	(0.173)	(0.254)
Client relationship	0.362*	0.315**	0.271	0.017	0.014	0.098	0.021	−0.040	0.421
	(0.187)	(0.176)	(0.260)	(0.177)	(0.167)	(0.258)	(0.176)	(0.166)	(0.256)
Auditor dependence	−0.073	0.174	0.079	0.129	−0.027	−0.385	−0.108	−0.188	−0.344
	(0.169)	(0.176)	(0.228)	(0.161)	(0.167)	(0.223)	(0.163)	(0.169)	(0.224)

Tab. 4: Ordinal regression analysis – Part 2

Factors identified	Dependent variable (group analyzed)								
	Auditor position			*Negotiator position*			*Client position*		
	Non Big 4	Auditor tenure	Partner	Non Big 4	Auditor tenure	Partner	Non Big 4	Auditor tenure	Partner
	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Model validation									
Pseudo R^2	0.162	0.181	0.220	0.179	0.062	0.086	0.075	0.070	0.147
LR statistic	35.290	37.150	33.970	43.260	14.150	12.760	18.420	15.690	23.370
Prob.	0.000	0.000	0.000	0.000	0.078	0.120	0.018	0.047	0.003
AIC	2.569	2.401	2.675	2.705	3.009	2.944	3.043	2.953	2.963

Note: Short definition of the groups under analysis: non Big 4 – auditors that do not work in Big 4 firms; audit tenure – auditors that have at least 3 years contractual relationship with the same client; partner – members of audit firms that are either partners or managing partners (CEOs). * 0.01 significance level; ** 0.05 significance level.

Source: own

when related to highly specific industries), or soft skills the staff should have, such as communication skills. This result is in line with Maresch et al. (2020), who have underlined the fact that both auditors and CFOs are more willing to compromise on the negotiation process as they perceive their counterparty as highly competent. However, auditors could gain this negotiation leverage as much as the prove to be constructive in discussion with the client's management, coming up with solutions that are beyond the audit adjustments proposed, supporting the client to optimize their processes, systems and tools and create value (Perreault & Kida, 2011).

Second, we observe the relevance of going concern in case auditors are willing to choose rather more compromising negotiation tactics (e.g., make concessions in order to get management acceptance for audit adjustment) or even conceding negotiation tactics (e.g., try to meet management needs) (e.g., Model 15: β = 0.369, Sig. = 0.048). Those results are justifiable from the perspective of auditors' lower risk tolerance to potential future higher clients' scrutiny, which could increase the probability of litigation costs for the auditor and significant deterioration of its reputation in the market (Carson et al., 2013). In those circumstances, auditors generally ask for further supporting evidence and perform additional testing (including sample increase), sometimes ask for early involvement in the process of financial statements preparation or disclose critical audit matters on the audit report.

Further, in Tab. 5, we assess the moderating effect of auditors' choice for the two types of negotiation tactics on the CatPCA dimensions previously analyzed. The association between variables is mainly driven by the expected correlation between them, as supported by the literature.

One notable difference between these results compared to the previous one presented is found in the case of the relevance of the *auditor proficiency* construct, which seems to be intensified in case auditors use contending negotiation strategy-related tactics (e.g., Model 19: β = −0.365, Sig. = 0.050). The results show that the more oriented the auditors' positioning toward compromising strategies, the lower is perceived the role of auditors' experience, expertise and communication skills, in line with other studies (Gibbins et al., 2010; Perreault & Kida, 2011; Trotman et al., 2011). Additionally, as Maresch et al. (2020) noted, both auditors and CFOs are more willing to compromise on the negotiation process as they perceive their counterparty as highly competent.

Therefore, a positive client's perception of auditors' competencies, in conjunction with a more contending position of negotiation of the auditor, increase the likelihood that clients provide concessions in the negotiation process.

Tab. 5: Ordinal regression analysis

Interaction effects	Dependent variable		
	Auditor position	*Negotiated position*	*Client position*
	(19)	(20)	(21)
Financial risk* × *aggressive strategy	0.186	0.168	−0.152
	(0.127)	(0.125)	(0.156)
Audit risk* × *aggressive strategy	−0.084	−0.014	−0.203
	(0.149)	(0.142)	(0.146)
Noncompliance client* × *aggressive strategy	−0.488**	0.413**	0.344**
	(0.196)	(0.190)	(0.201)
Contract client* × *conservative strategy	0.192	−0.027	0.156
	(0.136)	(0.117)	(0.121)
Auditor proficiency* × *aggressive strategy	−0.356**	−0.490**	−0.666**
	(0.196)	(0.193)	(0.364)
Governance client* × *aggressive strategy	0.184	0.037	0.220
	(0.168)	(0.165)	(0.168)
Relationship* × *conservative strategy	0.230**	0.010	−0.017
	(0.116)	(0.109)	(0.110)
Auditor dependence* × *conservative strategy	−0.023	−0.125	−0.032
	(0.134)	(0.128)	(0.130)
Model validation			
Pseudo R^2	0.073	0.035	0.048
LR statistics	20.060	10.460	14.310
Prob. (LR statistics)	0.010	0.234	0.074
Akaike info criterion (AIC)	2.746	3.054	3.078

Note: The interactions considered in the model are driven by expected associations drawn up by the literature.

Source: own

Conclusions

The current research brings insights on the auditor-client negotiation outcome and the dynamics behind their interactions, in case of an emerging but highly complex economy, Romania. As emphasized by theories such as the power-dependence theory or the CAN dynamic theory, auditors' choice for a negotiation strategy is essential in concluding on the final auditor opinion, what audit adjustments are to be disclosed and which ones to be waived for the next period. Despite the need for audit tenure that facilitates building a trustful auditor-client relationship, the results raise awareness of the risks concerning auditors' independence and objectivity when concluding on financial statements quality. Uncertainty auditors face under client's pressure and dynamics of the balance of auditors and clients power of negotiation behind their long-term relationship represent the main drivers of auditors' choice for different negotiation strategies and related tactics.

If problems related to disagreements in legal requirements of accounting treatments are subject to auditors' willingness to compromise

under specific circumstances (level of auditors' deficiency exposure tolerance), serious concerns are pointed out by the clients' management more favorable position of negotiation, at least on the initial negotiation process stage, and especially in the context of a moderately effective institutional and regulatory framework. This reality represents premises for potential threats to auditors' independence and objectivity, with negative implications for the quality of the financial statements. Considering distributive negotiation strategies (contending, compromising, conceding) seem to be the first option of the auditors, at least on the initial negotiation process positioning. The results show auditors' openness to adopt both contending and compromising strategies, but less conceding strategies. The shift seems to be significantly influenced by the quality of the auditor-client relationship and client pressure through the tactics of audit fees negotiation or contracting prolongation discussions. Auditors reporting ongoing concern represent another key pillar of auditors' choice for negotiation tactics that are aimed to compensate for the negative effects of clients' mainly timing-concession strategic-related tactics, which generally lead to auditors depletion and audit adjustments severity deterioration. However, as the study reviews only the auditors' perspective of the negotiation process, consideration of auditor liability or auditor commercial dependence show to be insignificant, most probably because of auditors overconfidence in their competencies and abilities that can help them overcome risks of future litigation costs or deterioration of auditors' reputation on long-term.

Practical implications. Based on the results of this paper, we emphasize several practical implications for the profession.

First, we subscribe to professional organizations' efforts to raise awareness of the role of compliance with the ethics and code of conduct in the auditing practice. Compliance with ethical professional standards creates the premises for a long-term trust-based auditor-client relationship.

Second, we admit that compromising negotiation strategies adopted by auditors are not always the best solution for ensuring high-quality financial statements and lower auditor liability, as they could be subject to some clients' management framing and manipulation activities during audit evidence collection and reconciliation meetings discussion. Therefore, were applicable and cost reasonable, we would recommend auditors to adopt emerging technologies and innovative solutions that support audit fieldwork digitalization, including via use big data and audit analytics tools, accounting estimates accuracy and completeness checking using machine learning protocols, or valorizing blockchain and could computing benefits. Such solutions would enhance auditors' effectiveness and efficiency in the long term and decrease auditors' liability, at least from the perspective of lowering auditors' cognitive biases and their negative implications on the quality of financial statements.

Third, as we understand that auditors face various changes in the business environment that become more and more complex and volatile, we would invite auditors to assess the extent to which they are currently relying on subject matter experts, either coming from external third-party service providers, or from clients' human resources, looking for possible compensating quality controls that ensure sufficient, reliable and accurate audit evidence.

Fourth, considering the VUCA framework as a reference for describing the current dynamics of the evolving business models, auditors should understand that adopting more integrative negotiation strategies would benefit both the auditors and their clients through better customer satisfaction and support for value creation process through process, systems and corporate capabilities continuous improvements. On this direction, we would also recommend that auditors ask for early involvement in the decision-making concerning recurrent and emerging issues. Through efficient communication, commitment to a high level of trust and transparency, and sharing of information and best practices, integrative negotiation strategies would allow both auditors and clients to reach their objectives. However, this approach should not exceed barriers established via regulatory requirements or via shareholders' and other stakeholders' concerns, as they should first play their main role of the assurance service provider.

Limitations and research avenues. The study addresses the assessment of the relevance of various drivers of auditors' positioning on the negotiation process with clients, concerning the reconciliation of the severity of the audit findings and, respectively, the conclusion

on the auditor's opinion. However, we point out that the study has several limitations.

First, the results are limited to Romanian business environment, which could be subject of only partial generalizability, because of the specific of the local business landscape, including legal environment, auditing regulatory differences, industry structure or economic development. Second, the study does not capture the behavioral components of auditors' choice for a negotiation strategy, as auditors' personality traits influence both auditor skepticism, and potential biases on the insights provided. Third, we acknowledge this study reflects only the auditors' perspective, which could limit the insights of this paper if there is a significant misalignment between auditors' and clients' expectations (identities), deepening the audit expectations gap, with negative implications on clients' perception about audit quality. Fourth, the research design considered in this paper captures only partially the dynamics of dyads' evolving interactions. Nonetheless, we consider another future research path could be the evaluation of the moderating/mediating impact of the clients' dynamic capabilities that are expected to facilitate audit evidence traceability and reliability.

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A logistic regression approach to long-term bankruptcy prediction: The role of financial and non-financial indicators

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Abstract: *The main aim of the research is to examine the possibility of developing logistic regression (LR) model that could reliably predict the bankruptcy of Serbian companies three years in advance based on financial and non-financial variables. This is important both for business owners and external stakeholders. Owners can predict failure on time and define remedial measures and action plans in accordance with that. External stakeholders, on the other hand, can use these models to identify financial risks before deciding to start cooperation with a specific company. The main motive for the research stems from the lack of bankruptcy prediction models in the scientific community of the Republic of Serbia, especially when it comes to long-term prediction. It is necessary to predict bankruptcy early enough to be able to take measures. A prediction one year in advance, which is a common case in the existing literature, may be too late to preserve the business's future. According to the authors' findings, no long-term prediction models have been developed for the Serbian market. Existing traditional models are developed for foreign countries, meaning they are not suitable for developing countries like Serbia. The research sample includes 94 companies of all sizes and is balanced: half of the companies are healthy, and the other half are bankrupt. A total of 36 financial and 7 non-financial independent variables are included in the modelling. Financial analysis is done in MS Excel, while statistical analysis (logistic regression) is done in IBM's SPSS program v. 26. The research results demonstrate that statistical and financial analyses are effective for bankruptcy prediction modelling, considering that the generated model has significant predictive (classification) power of 80%.*

Keywords: *Bankruptcy, insolvency, statistics, strategy, financial analysis, modelling.*

JEL Classification: *G33, M40, C44, C52.*

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Introduction

Insolvency is always an actual and important topic. Kovacova et al. (2019) claim that the issue of bankruptcy prediction is spread worldwide. Various explanatory variables and techniques have been used in the construction of bankruptcy prediction models. A company is said to be insolvent or under financial

distress if it is unable to pay its debts as they become due, which is aggravated if the value of the firm's assets is lower than its liabilities (Becerra et al., 2005).

According to Maras and Kozar (2021), bankruptcy proceedings in the Republic of Serbia have been prescribed by the Law on bankruptcy (The Republic of Serbia) and are initiated by the petition of the creditor, debtor or liquidator as authorized petitioners. Adopting a positive decision on such petition, in case the court determines the existence of one of the prescribed legal bankruptcy conditions, represents the opening of the bankruptcy proceedings. The main aim of bankruptcy proceedings is to enable the most favourable collective settlement of creditors' claims by selling the property of a bankrupt legal entity (Kuster, 2022).

The main aim of the research is to develop logistic regression model for bankruptcy prediction three years in advance. Despite various models developed worldwide, the necessity of developing a specific model for the Republic of Serbia is present. The traditional performance rankings, such as return on equity and return on assets, are not sufficient indicators of business performance (Milosevic et al., 2021). Not many research papers in Serbia include non-financial variables, which is the added value of the research. In addition, to the best authors' knowledge, no research has been conducted for the Serbian economy to predict bankruptcy three years in advance.

The main motive for the research stems from the fact the existing bankruptcy prediction models are, in most cases, developed for other countries that have different legal, accounting, and other requirements. Bankruptcy predictions are not explored enough in Serbia, nor in the Balkans, which emphasises the importance of this research. Alihodzic (2013) and Muminovic et al. (2011) confirmed that the existing models are not always suitable for the Serbian market. Nikolic et al. (2018) state that one of the biggest problems in the Serbian economy is a large number of bankruptcies in the SME sector. Furthermore, according to the data published by the Business Registers Agency (2023), the bankruptcy rate for 2022 is 4.3%, with 5,817 companies being in the bankruptcy proceedings (out of 135,490). This nominates Serbia as an interesting research field, considering the fact the current bankruptcy in the EU is 3.1% (Trading Economics, 2024). Bankruptcy prediction models support the economic stability and growth of Serbia by identifying vulnerable businesses at an early stage. This enables stakeholders to define intervention measures and reduce risks. Besides the above-mentioned, bankruptcy prediction modelling is important as a support for better decision-making in developing countries such as Serbia.

Through a comprehensive review of existing research encompassing a wide range of bankruptcy prediction models (e.g., Bellovary et al., 2007; Ratajczak et al., 2022), it has been determined that the overall accuracy of bankruptcy prediction models generally falls within the following range: 65–85% (for prediction three years in advance). Many authors, e.g., Du Jardin, 2009; Sharma and Mittal (2024), stated that, besides financial ratios, the non-financial variables are important in bankruptcy prediction. That being said, the research hypothesis is defined as follows:

H1: Bankruptcy in the Republic of Serbia can be predicted three years in advance with an overall accuracy of at least 70% using logistic regression that incorporates both financial and non-financial indicators.

H1.1: The logistic regression algorithm can detect patterns in data that predict bankruptcy for Serbian companies three years in advance, achieving an overall accuracy of at least 70%.

H1.2: Financial indicators serve as significant predictors of bankruptcy in Serbia three years in advance, with at least one financial ratio included in the final model.

H1.3: Non-financial indicators serve as significant predictors of bankruptcy in Serbia three years in advance, with at least one indicator included in the final model.

The research is organized as follows: the first section includes an overview of the existing literature related to bankruptcy and financial distress predictions. Afterwards, the sample and research methodology are presented. The fourth section is split into two primary sections. The first one explains model development, while the second section shows model accuracy testing. The last section is related to concluding remarks.

1 Theoretical background

Shi and Li (2019) generated a review of bankruptcy prediction models based on 321 most

Tab. 1: Bankruptcy prediction models – review

Classical statistical methods		
Ranking	**Method**	**Number of papers**
1	Logistic regression (logit)	123
2	Discriminant analysis	52
3	Multivariate discriminant analysis and *Z*-score	33
4	Hazard	19
5	Logit and probit	7
6	Probit	6
Machine learning and artificial intelligence models		
Ranking	**Method**	**Number of papers**
1	Neural network	56
2	Support vector machine	32
3	Decision tree	21
4	Generic algorithm	20
5	Fuzzy	17
6	Rough set	13
7	Data mining	11

Source: Shi and Li (2019)

relevant research papers. As can be seen in Tab. 1, the most frequently used technique in bankruptcy prediction is logistic regression (123/321 research papers). It is important to point out that one research paper can use more than one analysis method, and therefore, the sum of all the results is not exactly 321 papers.

The majority of business prediction models belong to the quantitative ones and their inputs are the results of technical financial analysis (Klepac & Hampel, 2018). In the literature review, we focused on the bankruptcy prediction models that are based on logistic regression only, as that is the technique used in the paper.

Ohlson (1980) is one of the pioneers of logistic regression analysis for the prediction of corporate bankruptcy. Results of the mentioned research indicate that net result to total assets and total debt to total assets are the best factors for bankruptcy prediction. Luoma and Laitinen (1991) developed a logit model with seven indicators based on a sample of Finnish firms. The predictive power of the model is 73.5% and 71% for bankrupt and non-bankrupt firms, respectively. Fletcher and Gross (1993) proposed logit model with 3 factors and general application. The classification power of the model is 71%.

Laitinen and Laitinen (2000) applied logit analysis and developed four models to predict bankruptcy even three years in advance. Stepwise logit model with ten variables included has an accuracy of 75, 65 and 67%, one, two and three years before bankruptcy occurs. Gaeremynck and Willekens (2003) proposed a logit analysis with 8 factors for Belgian private companies, and generated a model of 72% accuracy. Altman and Sebato (2007) generated a logistic regression model using unlogged and logged variables with total classification power of 75% and 87%, respectively. The focus was on small and medium entities (SMEs), and the sample consisted of 2,000 US firms. Hu and Ansell (2009) proposed logistic regression among other models they developed in the research. Variable selection was done using stepwise method and the final scope included 10 both internal and external variables. The developed LR model based on internal factors has

predictive power of 90, 87, and 82% for prediction of bankruptcy, one, two and three years in advance.

Tseng and Hu (2010) introduced four models for bankruptcy prediction, and one of them is logit model. Holdout approach was used, and a total of 77 companies was divided into training (61 firms) and testing sets (16 firms) on a random basis. Three variables were selected as important using the stepwise method: working capital to operational expenses, after-tax result to total assets and Δ cash to total liabilities. Developed LR model has predictive power of 77% for the training dataset and 86% for the testing set. Cho et al. (2010) suggested four LR models based on different variables selection (decision trees and stepwise methods). The sample included 1,000 companies, and ratio of failed and existing companies is 1:1. The highest performing model has predictive power of 72% and includes seven profitability, liquidity, activity, stability, labour productivity but also growth ratios. Yoon and Kwon (2010) generated LR model based on a sample of 10,000 companies. The number of solvent and insolvent companies is equal. The final model has a classification power of 70%.

Divsalar et al. (2012) based their research on a 136-firm sample, which was not balanced. Developed LR model includes four variables (profitability, solvency and liquidity scope) after reduction and has 76% classification power for testing dataset. Shie et al. (2012) included 54 companies in the research and developed model that has 73% predictive power, based on profitability, leverage, cash, liquidity and efficiency ratios. Stanisic et al. (2013) proposed LR modelling for Serbian companies. Developed model has precision of 75%. The model included raw variables (EBITDA and number of employees), but also turnover and debt ratios.

Tseng et al. (2014) developed LR model by combining five groups of ratio indicators (liquidity, leverage, turnover, profitability and market group) and generated three models for predicting bankruptcy up to three years in advance. The highest performing model has the following classification power for one, two and three years in advance (respectively): 79, 79 and 75%. Gordini (2014) applied LR modelling on a sample of 3,100 companies. The variables included are mostly in the scope of profitability, turnover, liquidity, debt and cash ratios. Those were selected based on VIF and stepwise analysis. Three models were developed. Accuracy of the models for bankruptcy prediction one, two and three years in advance follows (respectively): 69, 68 and 67%. Du Jardin (2015) developed LR multi-sector models (retail, construction and services) based on several test samples. The best performing model for all sectors has following classification power: 81% one year before bankruptcy, 78.5% two years before bankruptcy and 75.5% three years before bankruptcy. Variables included in modelling are: accounts payable turnover ratio, quick liquidity ratio, receivables turnover ratio, current ratio and net-income-to-shareholder-funds ratio.

Beslic Obradovic et al. (2018) generated log-regression model for insolvency prediction of Serbian companies one year in advance. Overall model accuracy 88% for the training sample and 82.5% for the testing dataset. The model includes the following ratio variables: working capital, self-financing and business effectiveness. Cheong and Ramasamy (2019) examined the bankruptcy prediction of 536 bankrupted and non-bankrupted banks in the USA. Logit approach was in place, and the conclusion is that high return on equity, as well as the adequacy of capital, have a negative impact on bankruptcy. Logit model for Greece firms, developed by Papana and Spyridou (2020), performs with the following classification power: 66, 62.5, and 68%, one, two and three years prior to bankruptcy, respectively. After variables reduction using *t*-test, total of 9 ratios (mostly profitability, liquidity, asset structure and solvency) was included in the modelling. Sricharoenchit and Hensawang (2021) developed a bankruptcy prediction model in the automotive industry based on a sample of companies from Thailand. Financial ratios and corporate governance variables were included. The final model has predictive power of 75%. Papík and Papíková (2024) suggested a comparison of log regression and machine learning methods based on a total of 6 techniques. The logistic regression model reached total accuracy of 68.2%.

2 Research methodology

This study presents a new bankruptcy prediction model specifically designed for Serbian companies, aiming to predict bankruptcy three years in advance. Our model stands apart from existing ones by using a unique set

of predictors. We independently calculated both financial and non-financial indicators in MS Excel, carefully screened the data, and carried out the model's training and testing in SPSS. This custom-built approach allowed us to tailor each step of the development process, ensuring the model's alignment with Serbia's regulatory and business environment.

The research sample includes 94 entities of various sizes from the Republic of Serbia. Half of the companies are solvent, and the other half went bankrupt. The sample is balanced based on methodology of many other authors that examined this subject, meaning there are 47 solvent and 47 bankrupt companies in the sample. Companies are not only balanced in terms of solvency/bankruptcy, but also in terms of age and turnover, as this sort of modelling requires an adequate sample. One part of the sample (80%) is used for model development, and the other part (20%) is used for model testing.

It is important to isolate the external impact of crises whenever possible and choose only stable business years in the sample. Therefore, we are focusing on the period before any time-lagged COVID-19 pandemic impacts. Companies that started bankruptcy proceedings

Tab. 2: Independent variables overview

Category	#	Symbol	Variable calculation method	#	Symbol	Variable calculation method
Financial variables	1	*ROA*	Net income/total assets	19	*Inv* / *S*	Inventory/sales
	2	*CR*	Current assets/current liabilities	20	*OI* / *TA*	Operating income/total assets
	3	*WC* / *TA*	Working capital/total assets	21	*OCF* / *S*	Operations cash flow/sales
	4	*RER*	Retained earnings/total assets	22	*NI* / *S*	Net income/sales
	5	*EBIT* / *TA*	EBIT/total assets	23	*LTD* / *TA*	Long-term debt/total assets
	6	*S* / *TA*	Sales/total assets	24	NW / *TA*	Net worth/total assets
	7	*QR*	(Current assets-inventories)/current liabilities	25	*C* / *CL*	Cash/current liabilities
	8	*TD* / *TA*	Total debt/total assets	26	*OCF* / *CL*	Operations cash flow/current liabilities
	9	*CA* / *TA*	Current assets/total assets	27	*WC* / *S*	Working capital/sales
	10	*DR*	Total liabilities/total assets	28	*Cap* / *A*	Capital/assets
	11	*C* / *TA*	Cash/total assets	29	*NS* / *TA*	Net sales/total assets
	12	*OCF* / *TA*	Operations cash flow/total assets	30	*NW* / *TL*	Net worth/total liabilities
	13	*OCF* / *TL*	Operations cash flow/total liabilities	31	*NCI*	No-credit interval
	14	*LIQ*	Current liabilities/total assets	32	*CFNI* / *D*	Cash flow (net income)/debt
	15	*OCF* / *TD*	Operations cash flow/total debt	33	*OCF*	Operations cash flow
	16	*QA* / *TA*	Quick assets/total assets	34	OE / *OI*	Operating expenses/operating income
	17	*CA* / *S*	Current assets/sales	35	*QA*/*S*	Quick assets/sales
	18	*EBIT* / *Int*	EBIT/interest	36	*S* / *Inv*	Sales/inventory
Non-financial variables	1	LOG_*TA*	Log(total assets)	5	Ln(*S* / *Inv*)	Log(sales/inventory)
	2	Headcount	Total number of employees	6	Log(*S*)	Log(sales)
	3	*L* / *C*	Labour/capital employed	7	Ln(*Age*)	Ln(operating years before bankruptcy)
	4	*OY*	Operating years before bankruptcy	–	–	–

Source: own

in 2020 are considered as bankrupted. The others still operating in the mentioned year are considered healthy. Data from the three business years preceding the bankruptcy declaration are utilized for calculating variables, as the primary goal of the research is to develop a model capable of accurately predicting bankruptcy three years ahead.

As presented in Tab. 2, total of 36 financial variables and 7 non-financial variables is included in the modelling. Financial variables are selected based on research of Bellovary et al. (2007), while non-financial variables were proposed by the following authors: Frydman et al. (1985), Tian and Yu (2017), Leshno and Spector (1996), Barniv et al. (1997), Park and Han (2002). Data for independent variables calculation is available on the Serbian Business Registers Agency website.

Status of solvency or bankruptcy is a dependent variable. In order to perform statistical modelling, this variable has been coded as follows: 0 = bankrupted entity and 1 = solvent entity. IBM's SPSS v.26 program and binary LR (logistic regression – LR), with "Stepwise – Forward: LR" algorithm is used for statistical modelling. Field (2009) stated that in case of forward LR algorithm, computer begins with a model that includes only a constant and then adds single predictors to the model based on specific criteria. The criteria is the value of score statistic: the variable with the most significant score statistic is added to the model. Therefore, this methodology is the right choice when no previous research is available or when a lot of independent variables are included in the analysis initially. LR uses the log-ratio to assign a company to either bankrupt or non-bankrupt class (Veganzones & Séverin, 2018). Logistic regression is a widely used statistical technique. It is used to predict the probability of an event's occurrence by fitting data onto a logistic curve. Logistic regression estimates the value of two class labels or sequence variables (Tsai & Hsu, 2011). Logistic function can be expressed as follows:

$$P(bankruptcy) = \frac{1}{1 + e^{-z}} \quad (1)$$

where: P – probability of default; z – explanatory variables linear regression. If z is given input, its output is $f(z)$.

The definition of variables of input z follows:

$$z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_k x_k \quad (2)$$

where: β_0 – intercept; β_1, β_2, β_k – coefficients of x_1, x_2, x_k. When all the independent variables are equal to zero, the intercept is the z value.

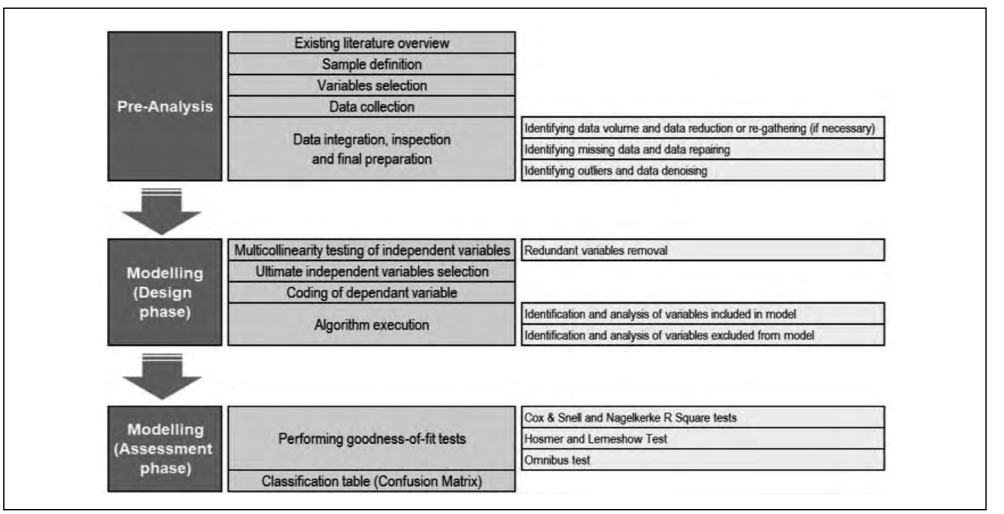

Fig. 1: Research framework

Source: Kuster (2023)

The quality of the developed models will be examined using the following tests: Cox and Snell R^2, Nagelkerke R^2, Hosmer and Lemeshow, Omnibus and Wald. Also, confusion matrix will be in place with the following indicators: accuracy, precision, recall/sensitivity and specificity:

$$\text{Accuracy} = \frac{True_{positive} + True_{negative}}{True_{positive} + True_{negative} + False_{positive} + False_{negative}} \quad (3)$$

$$\text{Precision} = \frac{True_{positive}}{True_{positive} + False_{positive}} \quad (4)$$

$$\text{Recall} = \frac{True_{positive}}{True_{positive} + False_{negative}} \quad (5)$$

$$\text{Specificity} = \frac{True_{negative}}{True_{negative} + False_{positive}} \quad (6)$$

The whole research framework indicating a step-by-step program is presented in Fig. 1. The research consists of three phases: pre-analysis, model design phase and model testing phase.

3 Results

3.1 Bankruptcy prediction model – Design phase

According to Salmeron et al. (2018), the presence of high collinearity in a regression model suggests that the conclusions drawn from the analysis may be unreliable. Multicollinearity often occurs in analyses due to high intercorrelation of variables (Gasic et al., 2023). Collinearity detection has to be the first step in every statistical analysis. Analysis is done via variance inflation factor (VIF). VIF analysis was conducted for all the independent variables.

Tab. 3: Variance inflation factor (VIF)

Variables	Collinearity statistics	
	Tolerance	VIF
RER	0.455	2.196
OCF/TL	0.698	1.434
LIQ	0.712	1.405
QA/TA	0.539	1.856
EBIT/Int	0.808	1.238
OI/TA	0.628	1.591
OCF/S	0.410	2.440
C/CL	0.620	1.614
OCF/CL	0.561	1.783
NW/TL	0.396	2.523
NCI	0.765	1.308
LOG_TA	0.448	2.230
OCF	0.525	1.906
OE/OI	0.458	2.181
S/Inv	0.465	2.151
L/C	0.496	2.017
Ln(*Age*)	0.650	1.538

Note: Coefficients – dependent variable: status 0/1.

Source: own

Cohen et al. (2003) and O'Brien (2007) stated that VIF values higher than 10 indicate a problem. Menard (2001) claims that VIF value higher than 5 is cause for concern. After the removal of redundant variables, the problem of multicollinearity is not present since no value exceeds 3.0. Only variables that passed the test are listed in Tab. 3.

As previously mentioned, stepwise forward logistic regression is used. The main advantage of this method is the fact that this algorithm selects only those variables that have a huge impact in outcome prediction, which further leads to stable models without redundant variables and overfitting. The bankruptcy prediction model was generated in three steps, where the third is the final with the best accuracy (Tab. 4).

It is worth mentioning that the parameters for all three steps will be presented as a part of the research and modelling process, but the analysis will always be focused on the final model parameters – Step 3. Three variables (*RER*, *OCFCL* and LOG_*TA*) are included in the final equation for bankruptcy prediction. In Tab. 5, we tested the importance of the selected variables, i.e., what happens if some of them are removed. Since the "Sig. of change" is lower than the confidence level 0.05, it can be concluded that all three variables contribute significantly to the model and, therefore, should remain in the equation.

Tab. 4: Variables included in the bankruptcy prediction model (variables in the equation)

Step	Variable	B	S. E.	Wald	df	Sig.	Exp (B)
Step 1[a]	*RER*	5.395	1.636	10.878	1	0.001	220.403
	Constant	−1.004	0.364	7.596	1	0.006	0.366
Step 2[b]	*RER*	7.126	2.035	12.256	1	0.000	1,243.314
	OCF/CL	0.459	0.369	1.542	1	0.214	1.582
	Constant	−1.220	0.399	9.370	1	0.002	0.295
Step 3[c]	*RER*	7.397	2.092	12.504	1	0.000	1,630.993
	OCF/CL	0.625	0.281	4.969	1	0.026	1.869
	LOG_*TA*	−1.388	0.496	7.827	1	0.005	0.250
	Constant	6.224	2.638	5.566	1	0.018	504.920

Note: a – variable(s) entered on step 1: *RER*; b – variable(s) entered on step 2: *OCF/CL*; c – variable(s) entered on step 3: LOG_*TA*.

Source: own

Tab. 5: Selected variables removal testing (model if term removed)

Variable		Model log likelihood	Change in −2 log likelihood	df	Sig. of the change
Step 1	*RER*	−52.679	16.778	1.000	0.000
Step 2	*RER*	−50.857	20.700	1.000	0.000
	OCF/CL	−44.290	7.567	1.000	0.006
Step 3	*RER*	−46.334	21.275	1.000	0.000
	OCF/CL	−42.402	13.412	1.000	0.000
	LOG_*TA*	−40.507	9.622	1.000	0.002

Source: own

Developed logistic regression models for predicting bankruptcy three years in advance can be written mathematically as follows:

$$P(x) = \frac{1}{1 + e^{-(6.224 - 1.388\ LOG(TA) + 0.625\ OCFCL + 7.397\ RER)}} \quad (7)$$

3.2 Bankruptcy prediction model – Assessment phase

To begin with, Wald test results are presented in Tab. 5. This test indicates if an independent variable has a statistically significant impact on the observed dependent variable. In other words, it demonstrates if a specific financial or non-financial variable is important for bankruptcy prediction. Considering the fact that *p*-value for this test (Sig.) is lower than 0.05 in case of all the variables, it can be concluded that the selected indicators have a significant impact on prediction power of the developed model.

The omnibus test can be used to analyse whether or not the model is reliable. It demonstrates how well the LR model predicts results, and how well this model predicts the risk (Pallant, 2009). When significance for Omnibus test (Tab. 6) is less than 0.05, model is considered to be well-fitted. The developed model is well-fitted taking into account the significance level that is lower than 0.05.

Tab. 6: Omnibus tests (tests of model coefficients)

Step	Item	Chi-square	df	Sig.
Step 1	Step	16.778	1.000	0.000
	Block	16.778	1.000	0.000
	Model	16.778	1.000	0.000
Step 2	Step	7.567	1.000	0.006
	Block	24.345	2.000	0.000
	Model	24.345	2.000	0.000
Step 3	Step	9.622	1.000	0.002
	Block	33.967	3.000	0.000
	Model	33.967	3.000	0.000

Source: own

Tab. 7: Cox & Snell and Nagelkerke *R* tests (model summary)

Step	−2 log likelihood	Cox & Snell *R* square	Nagelkerke *R* square
1	88.580	0.198	0.264
2	81.013	0.274	0.365
3	71.392	0.360	0.481

Source: own

According to Beslic Obradovic et al. (2018), the measure of R^2 ranges from 0 to 1, and values higher than 0.4 indicate that LR model is well-fitted. If the value of R^2 is 1, that means the independent variables (predictors) can completely explain the dependent variable, which is rarely the case in practice. Braun et al. (2013) stated that values in the range 0.24–0.32 are

considered as acceptable for these indicators. Given the values 0.36 and 0.48 (Tab. 7), it can be said that the bankruptcy prediction model is well-fitted.

The Hosmer-Lemeshow test (Tab. 8) is based on the calculation of λ^2 observed (actual) and predicted (expected) value of the dependent variable. It compares the original variables and prediction, in other words, it compares if there is a statistically significant difference between them (Pallant, 2009). Zenzerovic and Perusko (2009) stated that a model is well-fitted when Hosmer and Lemeshow test exceeds the level of 0.05. Considering the significance levels for the developed model, it can be concluded that it is well-fitted.

Tab. 8: Hosmer and Lemeshow test

Step	Chi-square	df	Sig.
1	9.171	7	0.241
2	11.527	8	0.174
3	7.948	8	0.439

Source: own

Tab. 9: Confusion matrix

Observed			Predicted					
			Selected cases (status 0/1)		Percentage correct (%)	Unselected cases (status 0/1)		Percentage correct (%)
			0	1		0	1	
Step 1	Status 0/1	0	29	9	76.3	5	4	55.6
		1	16	22	57.9	5	4	44.4
	Overall percentage (%)				67.1			50.0
Step 2	Status 0/1	0	30	8	78.9	5	4	55.6
		1	15	23	60.5	4	5	55.6
	Overall percentage (%)				69.7			55.6
Step 3	Status 0/1	0	30	8	78.9	6	3	66.7
		1	7	31	81.6	2	7	77.8
	Overall percentage (%)				80.3			72.2

Note: Classification table – the cut value is 0.500.

Source: own

The overall accuracy of the final developed model is 80.3% (72.2% for testing sample). The precision of the model is 78.9% (66.7% for testing sample). Recall (sensitivity) has value of 81.1% (75.0% for testing sample). Specificity of the model is 79.5% (70.0% for the testing sample). All the results are presented in Tab. 9.

4 Discussion

The developed models are useful for business owners, suppliers, customers, and banks. On the one hand, business owners can calculate the LR equation using their ratios and non-financial data and, therefore, identify whether there is a risk of bankruptcy. On the other hand, the same process can be executed by all

the other external stakeholders. Detailed statistical analysis with explanations can be useful for other authors as a starting point for further research that is based on logistic regression. Also, careful selection of variables can be useful for future research to develop new bankruptcy prediction models using different samples. An important contribution of this research is the inclusion of both financial and non-financial variables, but also development of the model that predicts bankruptcy three years in advance. In most cases, predicting bankruptcy for only one year before its occurrence does not leave enough time for the application of any healing measures. Significant advantage of logistic regression models compared other machine learning models (e.g., decision trees, neural networks) is the fact that everyone can use the regression equation easily by inputting specific values for the variables (ratios); there is no black box dilemma.

The research has several limitations. To begin with, model is developed as general, meaning it can further experience difficulties trying to classify a company as part of some specific economic activity. The idea for further research is to collect a sample of companies that belong only to one economic activity and develop activity-based model. Also, the accuracy of prediction is mainly driven by the correctness of financial statements. Furthermore, the research sample is relatively small, but that limitation is compensated by using advanced statistical program and careful data analysis. Another idea for the next research is to involve more observations in the sample, or even to develop a model that could be applicable for all Balkan countries. To conclude with, this model does not include any macroeconomic variables, and those are important for predicting bankruptcy in the long run. Future research should include macroeconomic and some other non-financial variables in order to raise the classification power of the model.

The developed model that predicts insolvency three years in advance is a significant advancement in Serbian economic theory and practice. Three parameters are identified as important for the prediction: retained earnings ratio, operations cashflow to current liabilities and logarithm of total assets. Retained earnings are an important indicator, demonstrating cumulative profits of a company. Higher levels of retained earnings indicate that the company is capable of generating profits. Companies with high retained earnings are less dependent of external financing. Low ratio of retained earnings to total assets may be an indicator of higher bankruptcy risk, due to reliance on external debts and insufficient profits for reinvestment. Strategies like cost controlling and revenue boosting, as well as rising operational efficiency are convenient way to boost retained earnings. When it comes to log value of total assets, it is important that larger assets base means higher collateral for secured financing. Companies should work on increasing of their assets base through acquiring new technologies, as well as entering new markets. Operational cashflow compared to current liabilities demonstrates if a company is able to cover its short-term obligations using cash generated only from operations related to the core business. Higher values of the indicator are a sign of better liquidity. Companies should strategically work on optimizing their cash flows and building a sustainable cash pool from their core business activities. The first step in the mentioned process is optimization of working capital, but also reduction of unnecessary expenses.

Conclusions

Bankruptcy will never be outdated; it is always current, since there is no economy that is not affected by companies' insolvency. This question is especially important for developing countries like Serbia. It is important to develop prediction models specifically for one country due to differences in economic situation, business climate, legal and other requirements. Bankruptcy prediction models are treated as tools of higher financial analysis (Kubenka et al., 2021). There are many differences and disagreements about the idea and how to apply the methods of modern accounting analysis, and there is a certain number of differences regarding the range and limits of modern accounting analysis (Majstorovic, 2016). A bankruptcy prediction model based on logistic regression allows stakeholders to reliably assess a company's financial health using just a basic understanding of ratio indicators, without the need for in-depth accounting knowledge or expertise in financial analysis.

As previously mentioned, not many research papers globally were oriented towards developing models that could predict bankruptcy three years in advance. Best to the author's knowledge, no research in Serbia has covered

this wide prediction timeline yet. The developed model for prediction of bankruptcy three years in advance has overall classification accuracy in the range of 70–75% (for the test sample), together with a model of Tseng et al. (2014). The developed model has lower performance than the following prediction models: Hu and Ansell (2009) and Du Jardin (2015). The developed Y-3 LR model performs better than the following prediction models: Laitinen and Laitinen (2000), Gordini (2014) and Papana and Spyridou (2020).

The research followed a structured process, starting with a relevant literature review in order to establish solid base knowledge. Afterwards, a sample of 94 entities was defined (divided as 80%:20% = training:test sample), followed by selection of explanatory variables. The research initially included a combination of more than 40 financial and non-financial variables and the final developed model includes three of them. In the first step, 17 variables out of the initial 43 were selected using VIF analysis, as this test indicates the existing of multicollinearity that is not acceptable in LR modelling. Further reduction is done via stepwise LR algorithm where only 3 variables were selected in the third step as important for the model (*RER*, *OCFCL* & LOG_*TA*). The model's performance was evaluated through goodness-of-fit tests (Omnibus test, Cox & Snell test, Nagelkerke test, and Hosmer & Lemeshow test) and assessed with a confusion matrix for both training and testing datasets, providing a robust validation of the model's predictive accuracy and relevance within Serbia's economic environment. Final accuracy of the developed model is 80% (72% for the test sample). In other words, this study resulted in a new, unique prediction model aiming to predict bankruptcy in Serbian three years before it occurs.

Practical findings of the research highlight several important aspects: i) warning signs identification – the model is easy to use, and it enables the stakeholders to take proactive measures; ii) financial institutions support – the developed model is useful for investors, creditors and other institutions in the Republic of Serbia as it helps in managing risks and supports decision making; iii) promotion of sustainable business – bankruptcy prediction models like this motivate companies to take steps to improve financial health by addressing the problems that are identified by the model, and that further leads to overall business environment stability; and iv) regulatory enhancements – the developed model showed that operations cashflow compared to current liabilities is one of the important predictors of bankruptcy. Poor cash management leads to financial problems, and therefore regulatory authorities may use this insight to launch new initiatives, like offering favourable loans to support businesses and help them maintain stable cashflows.

The idea for future research is to include even macroeconomic variables in the modelling to rise prediction accuracy. Also, the suggestion is to provide greater research sample or to develop a bankruptcy prediction model for specific economic activity (manufacturing, trade).

Serbia, as a developing economy, faces distinct economic and legal challenges that influence the financial health of its businesses. The country is still navigating a period of economic transition, using a Serbian sample for the model ensures that it accurately reflects the country's specific economic and regulatory environment. This is crucial, as there is currently no model that predicts bankruptcy in Serbia with a three-year lead time. Neighbouring Balkan countries such as Croatia, Bosnia and Herzegovina, North Macedonia, and Montenegro share similar economic structures, legal frameworks, and industrial profiles. These nations also face typical challenges encountered by developing economies. As a result, the model developed for Serbia could be a useful foundation for these countries, though it would need to be adjusted for local differences, including variations in business practices. In essence, while the model is tailored to Serbia, it has the potential to be adapted for other Balkan countries with some refinement. Pilot testing the model in these countries would offer valuable insights into its cross-border applicability and help determine the necessary modifications for improved predictive accuracy.

To conclude with, auxiliary hypotheses are accepted:

i) Logistic regression algorithm is capable of identifying patterns in data related to predicting bankruptcy three years in advance as model of total accuracy of 80% was generated (72.2% for the test sample);

ii) Financial variables serve as significant predictors of bankruptcy in Serbia three years in advance as two of them are included in the final LR equation (*RER* and *OCFCL*);

iii) Non-financial variables indicators serve as significant predictors of bankruptcy in Serbia three years in advance as one of them is included in the final LR equation (Log_*TA*).

Therefore, the main hypothesis is accepted. Bankruptcy in the Republic of Serbia can be predicted three years in advance with an overall accuracy of at least 70% using logistic regression that incorporates both financial and non-financial indicators.

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A proposal of a relative weighted online 5-star rating system as a way to mitigate online reviews biases

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***Abstract**: Online ratings and reviews can be considered an electronic word of mouth regarding the quality of goods, products, or services. Reviews provide crucial information for customers, therefore significantly influencing their behavior, and they enable feedback to businesses from their customers, increase visibility, drive sales, help in developing a brand and building trust and reputation among consumers. However, the current 5-star rating system currently used on many Internet platforms such as Amazon or TripAdvisor suffers several drawbacks (biases) such as sentiment bias, polarization bias, non-discrimination bias, or vocal minority-silent majority bias. Therefore, the aim of the paper is to propose a new (weighted) relative 5-star rating system which takes into account reviewers' history (in the form of the average and variance of the past reviews) and transforms absolute aggregate ratings into relative ones, thus providing less biased information for consumers and businesses. In particular, the proposed system reduces sentiment bias and non-discrimination bias. Moreover, the proposed approach enables to reduce the influence of ratings made by bots or dishonest evaluators-humans. The real-world application of the proposed approach dealing with ratings of selected attractions in Madrid area is provided as well.*

***Keywords:** Bias, e-commerce, online reviews, online ratings, relative ratings.*

***JEL Classification:** M3, C81.*

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Introduction

Nowadays, online shopping becomes more popular than ever. Retail e-commerce sales are growing so fast that it is estimated that they will exceed USD 7 trillion in 2025 (Statista, 2022). In 2019, there were 1.92 billion digital buyers, and eCommerce sales accounted for 14.1% of retail purchases worldwide (Statista.com). In 2023, this amount is expected to grow to 22% (Statista, 2022). According to Statista (2022), the countries with the leading average eCommerce revenue per shopper are (from 2018): USA (USD 1,804), UK (USD 1,629), Sweden (USD 1,446), France (USD 1,228), Germany (USD 1,064) and Japan (USD 968).

Online ratings and reviews of goods and services play a substantial role in shaping businesses in the digital marketplace. They

provide feedback to businesses from their customers, increase visibility, drive sales, help in developing a brand, trust and reputation, and in spreading a word of mouth (Lackermair et al., 2013; Park & Nicolau, 2015; Willas, 2021). At the same time, they belong among one of the most trusted sources of consumer confidence in e-commerce decisions (Aral, 2013; Breinlinger et al., 2019). Nielsen (2012) found that online consumer reviews are the second most-trusted source of brand information after recommendations from friends and family (Aral, 2013). From customers' perspective, online reviews (including 5-star ratings) constitute a popular way of evaluating goods or services like hotels, restaurants, movies, books, and places, thus providing useful information for purchase choice to other consumers. It has been found that online reviews are the basis for growing share of internet users to make a choice (Floyd et al., 2014; Lin et al., 2011; Riegner, 2007; Sun, 2012). In particular, positive reviews may positively influence the product-related attitudes and buying behavior of potential buyers (Floyd et al., 2014; Park et al., 2007), and have a large impact on sales (Chen et al., 2018; Helversen et al., 2018; Li et al., 2020; Wu et al., 2015; Zhang et al., 2013; Zhu & Zhang, 2010). On the other hand, the proportion of negative reviews has strong negative impact on purchase decision of potential consumers (Weisstein et al., 2017). In particular, the 2023 ReviewTrackers online reviews survey (ReviewTrackers, 2023) found that negative reviews convinced 94% of consumers surveyed to avoid a particular business.

Another problem for Internet retailers is related to fake or dishonest reviews. Consumers use reviews for making purchasing decisions and when reviews are fake, consumers may mistakenly believe that a particular product is excellent, while the true experiences of users may be rather negative (Manning & Tutella, 2023). For example, TripAdvisor reported that they removed more than 2 million potentially fake reviews from their website in 2020. They found that in 97% of these cases, the culprit was the firm itself. The firm asked their employees or their family members to post positive reviews and even provided financial compensation to upload fake reviews (Manning & Tutella, 2023). Therefore, authorities such as the Federal Trade Commission (FTC) in the USA are preparing new regulations to fight fakery on online review platforms. European Union performed a sweep on online consumer reviews in 2021 by checking 226 major Internet websites. Consumer protection authorities concluded that at least 55% of the websites may violated the EU Unfair Commercial Practices Directive (European Parliament and Council, 2005) which requires truthful information to be presented to consumers in order to allow an informed choice. Authorities also had doubts for another 18% of websites (European Commission, 2024). Beck et al. (2023) focused on how review platforms can fight fakery and build consumer trust. They proposed five practices: monitoring, exposure, community building, status endowment, and identity disclosure. Big companies such as Google or TripAdvisor use machine learning (ML) algorithms to identify fake reviews based on sentiment (text) analysis, where natural language processing (NLP) tools are applied to extract reviews' features such as sentiment, polarity, subjectivity, readability, vocabulary, or grammar. Other ML approaches include network analysis tools applied to reviewers' network, analysis of reviewers' profiles, their temporal characteristics and images (Ennaouri & Zellou, 2022; Elmurngi & Gherbi, 2017).

In general, customer reviews are presented in two different forms on the websites of most online retailers: as aggregate rating scores expressed in a certain amount of stars, circles or other icons, and as individual reviews in full wording. In this paper, we deal with the former kind and, specifically, we focus on 5-star rating systems used by many online retailers such as Amazon, Costco, or Walmart.

The simplified process of absolute rating systems is shown in Fig. 1.

Though online ratings/reviews are greatly helpful both for businesses and customers, they suffer several drawbacks caused by cognitive biases (a cognitive bias is a systematic error in thinking that occurs when people are processing and interpreting information) inherent to human minds (Fig. 2). In the context of online reviews, the following biases were identified in the literature.

i) The same rating or a review may correspond to different levels of sentiment for different reviewers because of the explicit preference differences in individuals. People differ in what they perceive as, e.g., very good (Breinlinger et al., 2019; Mazurek et al., 2021;

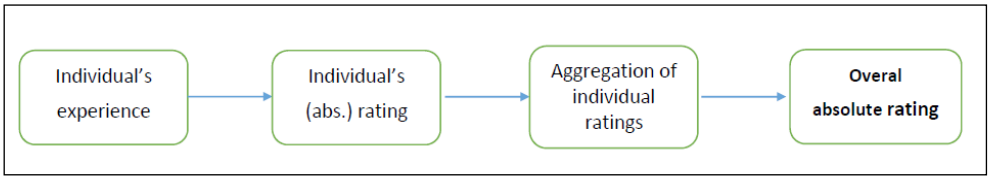

Fig. 1: Absolute rating system

Source: own

Wu & Liao, 2021). We will refer to this phenomenon as a sentiment bias.

ii) Customers lack incentives for providing truthful feedback (Breinlinger et al., 2019; Papaioannou & Stamoulis, 2005).

iii) Online reviews are susceptible to a polarization bias – customers with extreme experience (either very bad or very good) are much more likely to leave feedback than customers with moderate experience, thus creating selection biases in the form of a well-known J-curve or U-curve (Chamberlain & Smart, 2017; Park & Nicolau, 2015; Schoenmuller et al., 2019).

iv) Vocal minority and silent majority bias refers to the observation that only a small proportion of consumers provide a review or rating, while the majority refrains from expressing their opinion (Gao et al., 2015).

v) Simple 5-star rating systems are useful for identifying very low-quality products or suppliers. However, they fail to distinguish between good and great products or suppliers (Breinlinger et al., 2019).

vi) Online ratings are also prone to "grade" inflation or a "horde" effects, e.g., someone rates a restaurant as excellent, then it is likely that the following reviews will be excellent too (Aral, 2013; Breinlinger et al., 2019).

vii) Some reviewers always post the same number of stars for everything, making the reviews pointless. We will refer to this phenomenon as a non-discrimination bias.

Since the aforementioned drawbacks are well-known, ideas on how to overcome them are currently debated in the literature and specialized Internet magazines devoted to e-commerce (Aral, 2013; Askalidis et al., 2017; Breinlinger et al., 2019; Chamberlain & Smart, 2017; Ryan, 2016).

The aim of this paper is to propose a (weighted) relative 5-star rating system that mitigates at least some of the mentioned disadvantages (biases) of the absolute 5-star rating system. In particular, our system takes into account all past reviews of each customer (also called a reviewer hereinafter) at a given Internet platform and transforms a particular absolute rating of a given product or service into a relative 5-star rating. Furthermore, our approach allows to assign weights to each reviewer based on his/her experience and a variance of his/her ratings. In this way, several disadvantages (the sentiment bias or non-discrimination bias) of the absolute rating system are alleviated, thus providing less biased information for consumers and businesses. Moreover, the proposed approach may reduce the influence of ratings made by bots or dishonest human evaluators. To demonstrate the proposed approach, we provide a real-world application example in Section 2.

The paper is organized as follows: in Section 1 the (weighted) relative 5-star system is introduced along with an illustrative example, Section 2 provides a real-world application of the relative rating system. In Section 3, the advantages and limitations are briefly discussed, and Conclusions close the article.

1 Relative (weighted) 5-star rating system

An absolute 5-rating system aggregates all reviews as an arithmetic mean, where all reviews (reviewers) are treated equally (have the same weight). This system suffers several drawbacks or biases. However, by transforming the absolute ratings to relative ones, sentiment bias, polarization bias, and non-discrimination bias can be mitigated to a considerable extent.

If a reviewer who usually provides two or three stars evaluates a restaurant with four stars, is it not more informative than five stars

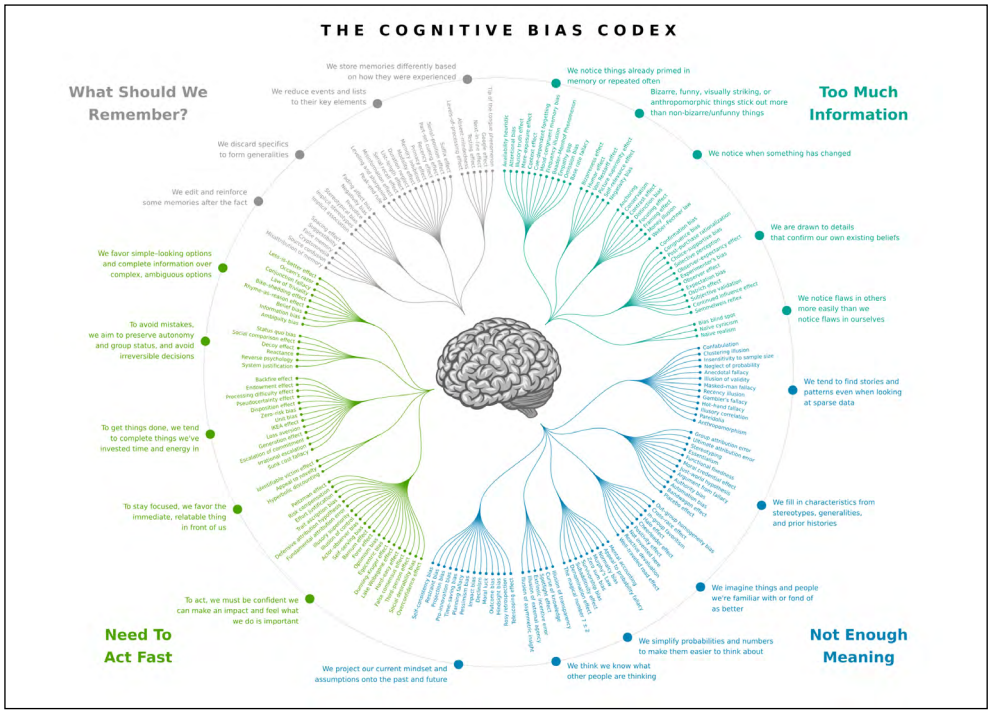

Fig. 2: **Cognitive biases**

Source: Backer (2022)

from a customer who gives five stars to every restaurant? To illustrate the problem in more detail, consider the following example.

Example 1. Consider two hotels, A and B and the 5-star rating system, where 5 stars express the best assessment by customers. Hotel A received 3 reviews (reviewers 1–3): 3*, 4* and 3*, which gives 3.33* in total. Hotel B received two reviews (from reviewers 4 and 5): 4* and 5*, with the total 4.5*. It seems hotel B is viewed more positively by customers; hence its quality is likely better. However, a more detailed inspection into reviews tells a different story (Tab. 1). As can be seen, all

Tab. 1: **Reviewers and their absolute 5-star ratings**

Reviewer	Hotel						
	A	B	C	D	E	F	Reviewer's average rating $\bar{r}_i$
1	3*	–	–	2*	1*	2*	2.0*
2	4*	–	2*	3*	2*	4*	3.0*
3	3*	–	2*	2*	1*	–	2.0*
4	–	4*	5*	5*	4*	–	4.5*
5	–	5*	5*	5*	5*	–	5.0*

Source: own

reviewers of hotel A provided a review higher than their average review, while reviewers of the hotel B provided only average or under average assessment.

To avoid problems with the individual scale perception (sentiment bias), we propose a relative 5-star rating system (from 1* to 5*), which takes into account reviewer's history in the form of the arithmetic mean of his/her reviews placed on a given Internet platform. The objective of the new system is to assign more fairly a new rating to an object (product) *j*.

Let r_{ij} denote the (absolute five-star) rating of the i^{th} reviewer of the j^{th} object, and let n_j be the number of reviewers of the object *j*.

The algorithm for the transformation from the absolute 5-star rating system into the relative 5-star system proceeds in the following steps.

Step 1. For an assessed object *j* on a given Internet platform find all n_j its reviewers with their absolute 5-star ratings r_{ij}, $i \in \{1, \ldots, n_j\}$, and let $\bar{r}_i$ be the average absolute star rating of the reviewer *i* calculated from his/her all ratings on the given platform.

Step 2. For each reviewer *i* and an object *j* calculate his/her relative rating of the object *j*, that is the difference of his/her absolute rating of the j^{th} object and his/her absolute average rating: $r_{ij} - \bar{r}_i$; where: $-4 < r_{ij} - \bar{r}_i < 4$ (the value close to 4 is obtained when the average absolute rating of a reviewer is near 1*, but he/she gives an objects 5*. Similarly, the value close to −4 is acquired when the absolute average rating of a reviewer is near 5*, but he/she gives an object only 1*).

Step 3. Aggregate individual relative ratings of all n_j reviewers of the object *j* from Step 2 into the final relative rating $T_j^{(1)}$ for the given object *j*.

$$T_j^{(1)} = 3 + \frac{1}{2n}\sum_{i=1}^{n_j}(r_{ij} - \bar{r}_i) \tag{1}$$

In Equation (1), the arithmetic mean of relative ratings of all n_j reviewers is linearly transformed from the open interval (−4, 4) to the open interval (1, 5). This transformation is simply given as $y = 1/2\ x + 3$, that is why coefficients 3 and 1/2 appear in Equation (1). In general, the relative 5-star rating is a real number unlike the absolute 5-star rating.

Alternatively, if a reviewer uses the scale from 1 to 10 stars, then, by analogy, the aggregate relative rating $T^{(2)}$ transformed into the (1, 5) interval is obtained as follows.

$$T_j^{(2)} = 3 + \frac{2}{9n}\sum_{i=1}^{n_j}(r_{ij} - \bar{r}_i) \tag{2}$$

In general, for any *K*-star rating scale from 1 to *K* (where: *K* is an integer greater than 1) the aggregate relative rating $T^{(3)}$ transformed into the (1, 5) scale again can be achieved as follows:

$$T_j^{(3)} = 3 + \frac{2}{(K-1)n}\sum_{i=1}^{n_j}(r_{ij} - \bar{r}_i) \tag{3}$$

Example 1 continued. Now, with the help of Equation (1), we can re-evaluate ratings of both hotels A and B from Example 1:

Hotel A: $T^{(1)}(A) = 3 + \frac{\{(3-2)+(4-3)+(3-2)\}}{6} = 3.5$

Hotel B: $T^{(1)}(B) = 3 + \frac{\{(4-4.5)+(5-5)\}}{4} = 2.875$

We can see that now hotel A is evaluated better than hotel B, which makes sense, since hotel A obtained above average reviews, while hotel B received only average to under average reviews.

The flowchart of the proposed relative rating system is shown in Fig. 3.

Another refinement to the relative 5-star rating system could be adding weights to each reviewer based on: i) the number of reviews; and ii) the variance of the reviews.

In the former case, reviewers with more reviews can be considered more experienced, thus acquiring greater weight. One suitable mathematical function that can be applied to express the degree of experience *E* is the logarithmic function (see the justification of the logarithmic transformation in De La Calle (2023)).

$$E_i = a \cdot \log(N_i + b) \tag{4}$$

where: N_i – the number of ratings provided by a reviewer *i*; $a > 0$ and $b \geq 0$ are constants; for simplicity, one can set $a = 1$ and $b = 0$.

Applying experience as a weight of a given reviewer in the process of aggregation ratings across the set of all reviewers, the final weighted relative 5-star rating $T^{(4)}$ for a given product or service *j* is obtained as follows:

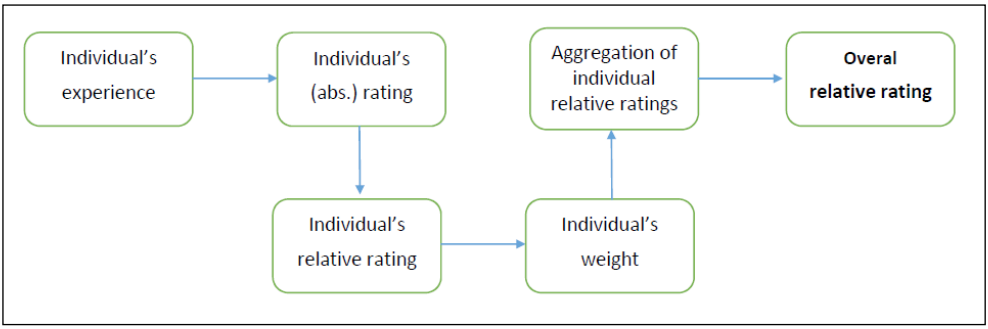

Fig. 3: **Relative (weighted) rating system**

Source: own

$$T_j^{(4)} = 3 + \frac{1}{2n}\sum_{i=1}^{n_j} E_i \cdot (r_{ij} - \bar{r}_i) \quad (5)$$

In the latter case, reviewers with greater variance in their reviews can be considered more adept at distinguishing the quality of evaluated objects, thus receiving greater weight. As a consequence, reviewers who rate every good or service with the same number of stars (with zero variance) would rightly receive a zero weight as their reviews do not contain any meaningful information.

In the latter case, which seems to be more natural, we suggest using the standard formula for (population) variance.

$$\sigma_i^2 = \frac{1}{N_i}\sum_{j=1}^{N_i} (r_{ij} - \bar{r}_i)^2 \quad (6)$$

where: i – a reviewer; r_{ij} – the (absolute 5-star) rating of the i^{th} reviewer of the j^{th} product on a given platform; $\bar{r}_i$ – the arithmetic mean of all his/her ratings on the platform.

Note that the minimal possible variance is 0, this is the case of reviewers who provide all reviews with the same amount of stars. On the other hand, maximum variance $\sigma^2 = 4$ is acquired in the case when a reviewer provides the same amount of 1* and 5* reviews and zero ratings with 2, 3 or 4 stars.

Applying the variance as a weight of a given reviewer in the process of aggregation star ratings across the set of all reviewers, the final weighted relative 5-star rating $T^{(5)}$ for a given product or service is obtained as follows.

$$T_j^{(5)} = 3 + \frac{1}{2n}\sum_{i=1}^{n_j} \sigma_i^2 \cdot (r_{ij} - \bar{r}_i) \quad (7)$$

Of course, the number of reviews and their variance can be considered simultaneously, which leads to the relative 5-star rating $T^{(6)}$.

$$T^{(6)} = \lambda T^{(4)} + (1 - \lambda) T^{(5)} \quad (8)$$

where: $\lambda \in [0, 1]$ is a parameter allowing shifting the weight from experience to variance and vice versa. Apparently, for $\lambda = 0$ we get $T^{(5)}$ and for $\lambda = 1$ we get $T^{(4)}$.

The proposed approach is illustrated on a real-world example in the following section.

2 Application – Rating of selected attractions in Madrid area

To show a real-world application of our proposed 5-star relative rating system consider the following ten attractions in or near Madrid (Fig. A1; Appendix). All ten objects were evaluated by customers on TripAdvisor web page (TripAdvisor uses 1 to 5 circles instead of stars). Altogether, 77 distinct reviewers provided their rating of all objects, some of them rated more than one object.

The absolute average ratings of all ten objects are shown in Tab. 2, second column. The best rated is Museo de Aeronautica and the worst one is a night-club Lady Madrid.

However, from history of individual reviewers who provided the reviews (which is not shown here due to personal data protection), the relative aggregate rating $T^{(1)}$ was acquired and the result is shown in Tab. 2, third column. As can be seen, the rating of the objects changed significantly. Now, the best assessed object is Cámara de Comercio, which was ranked seventh in the absolute star system, and the worst remains Lady Madrid.

Finally, the fourth column of Tab. 2 shows aggregated weighted relative 5-star ratings $T^{(5)}$ for all ten objects. This time, the best rated object is Cerro San Pedro, which was ranked second in both previous rating systems, the worst is still Lady Madrid. Differences among all three rating systems are graphically displayed in Fig. 4.

As for the ranking of all ten objects, they are shown in Tab. 3. Similarity of two rankings can be evaluated via Spearman's rank

Tab. 2: Rating of ten objects in Madrid area (in *)

Object	Absolute rating	Relative rating $T^{(1)}$	Relative weighted rating $T^{(5)}$
Hospital de Maudes	4.14	3.13	3.15
Cámara de Comercio	4.00	3.34	3.21
Museo de Aeronautica	4.75	3.00	3.31
Apartamentos Pl. Espana	3.56	2.84	2.62
Instituto Cervantes	4.42	3.07	3.00
Cerro San Pedro	4.50	3.20	3.40
Segovia	4.29	2.95	2.94
Lady Madrid	2.83	2.41	1.53
Martonela Goya	3.50	3.16	3.14
Cines Golem	4.42	3.17	2.99

Source: own

Tab. 3: Ranking of ten objects in Madrid area

Object	Absolute rank	Relative rank $T^{(1)}$	Relative weighted rank $T^{(5)}$
Hospital de Maudes	6	5	4
Cámara de Comercio	7	1	3
Museo de Aeronautica	1	7	2
Apartamentos Pl. Espana	8	9	9
Instituto Cervantes	3	6	6
Cerro San Pedro	2	2	1
Segovia	5	8	8
Lady Madrid	10	10	10
Martonela Goya	9	4	5
Cines Golem	4	3	7

Source: own

Tab. 4: **Rating and ranking of ten objects in Madrid area after bad bot's manipulation**

Object	Absolute rating (in *)	Ranking
Hospital de Maudes	4.45	5
Cámara de Comercio	4.00	7
Museo de Aeronautica	4.75	1
Apartamentos Pl. Espana	3.56	8
Instituto Cervantes	4.42	6
Cerro San Pedro	4.50	4
Segovia	4.51	3
Lady Madrid	2.83	10
Martonela Goya	3.50	9
Cines Golem	4.56	2

Source: own

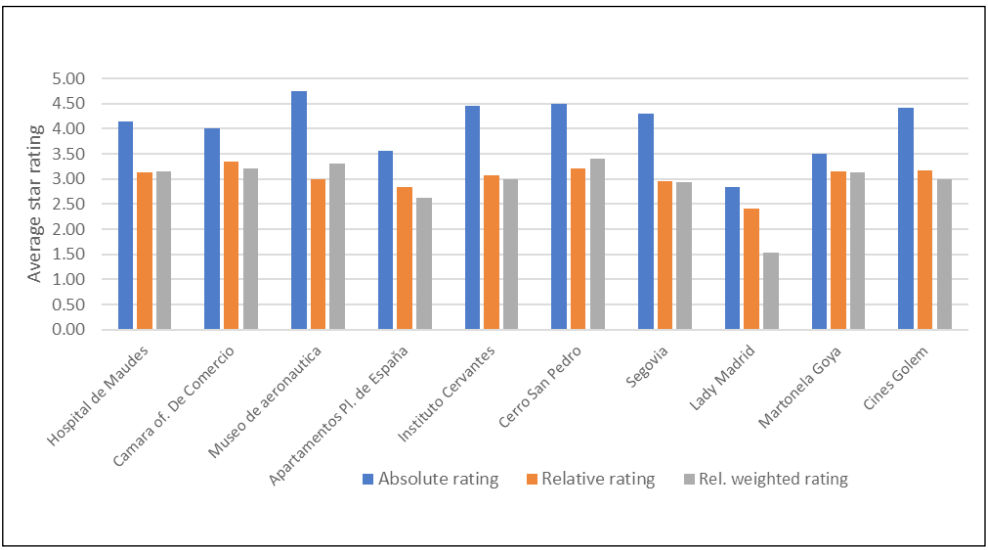

Fig. 4: **Aggregate ratings for all selected places of interest**

Source: own

correlation coefficient ρ. In our case, for the absolute ranking and the relative ranking ρ = 0.28, while ρ = 0.60 for the absolute ranking and the weighted relative ranking. Hence, in the latter case, both rankings were more similar. Further on, relatively low values of the correlation coefficient confirm that ranking of reviewed objects changed significantly under transformation to relative rating system.

The weighted relative rating with the aggregation function $T^{(5)}$, see Equation (7), reduces the possibility of rating manipulation (see also Discussion) by bad bots or dishonest reviewers. Consider, for example, situation when a bad bot wants to manipulate the rating shown in Tab. 2, column 2 (absolute ranking) in favor of three attractions not in the TOP 3: Cines Golem (placed 4th), Segovia (placed 5th) and Hospital des Maudes (placed 6th), see Tab. 3. The bot resumes four fake identities and places 5* rating to all three attractions under each identity. Then, the absolute rating (and order) of all ten attractions in Tabs. 2–3 changes, see Tab. 4. While Museo de Aeronautica retains the first spot, Cines Golem is second and Segovia third (Hospital de Maudes moved up from 6th place to 5th place). However, with the aggregation function $T^{(5)}$, this manipulation would not be possible no matter how many fake identities the bad bot generates. Indeed, each fake identity has zero variance in their ratings (all are 5* ratings) and therefore zero weight in the final aggregation of individual ratings.

3 Discussion and limitations of the proposed approach

As already mentioned, the absolute 5-star rating system suffers from many biases. The proposed (weighted) relative 5-star rating system reduces at least several of them, thus providing more reliable information for customers and businesses.

Firstly, the sentiment bias is based on the observation that different reviewers have different levels of sentiment towards the perceived quality of goods or services. Taking into account all reviews/ratings of a given reviewer at a given platform in the proposed relative 5-star system allows to establish his/her mean level of sentiment (as the arithmetic mean of all his/her ratings) and then a comparison between this average level and a particular rating of a given product is performed via transformations (1–3), thus reducing the sentiment bias. Another bias that is reduced by the proposed relative system is the non-discrimination bias. Reviewers who post mostly or solely the same (good or bad) ratings get very low (or zero) weight in the aggregation procedure for the derivation of the overall ranking of a given product. This is achieved by taking the variance of customers' ratings into account, see transformations (4–8). To some extent, the polarization bias is reduced as well, since reviewers with extreme experience tend to provide the same (again good or bad) ratings.

Another virtue of the proposed approach is the possibility of reducing influence of fake reviews generated by bots or dishonest evaluators. According to Fakespot Inc. report (Coleman, 2020), an online monitoring service, 42% of Amazon online reviews were categorized as unreliable. Comparably, around 36% of reviews from Walmart's online store were categorized similarly. A fake reviewer is likely to post constantly biased opinions, either overrated or underrated (e.g., only 1*s, or only 5*s). However, such a reviewer would attain very small or zero weight in the final aggregation of online ratings.

Apart from its obvious advantages the proposed rating system has also its limitations. The most obvious one is the need of calculating the arithmetic mean and variance of all previous reviews for all reviewers, which might be tedious and time consuming in the case of many reviewers with large numbers of reviews. This is why some software support might be considered in the future.

Further on, on some Internet platforms, it is impossible to find reviewers' history, hence our approach cannot be implemented.

Also, when a number of reviewers is large, reviewers with different sentiment levels will likely balance (cancel out) each other due to the law of large numbers, and the difference between absolute and relative star ratings will likely be rather small.

However, when the number of reviews is small, relative ratings might differ from absolute ones significantly as shown in the previous examples.

At last, but not least, the proposed relative 5-star rating system reduces only a small portion of biases mentioned before, therefore, it can be further adjusted and modified to make online reviews aggregations even less biased.

From a practical point of view, implementation of the proposed relative rating system into online retailer platforms would undoubtedly require not negligible amount of financial resource, nevertheless we believe more reliable reviews may compensate for supplementary costs.

Conclusions

The aim of this paper was to propose the relative (weighted) 5-star rating system as an alternative to an absolute 5-star star rating system commonly used for online reviews, which suffers from several drawbacks and biases.

The relative rating system enables to mitigate sentiment bias, polarization bias and non-discrimination bias, thus, in our opinion, providing less biased and fairer assessments of services, goods or other objects for both customers and businesses. In addition, assigning weights to individual online reviewers may reduce the influence of fake reviews generated by bots or dishonest evaluators.

Our future research will focus on comparisons of both rating systems, relative and absolute, and on developing a software tool able to transform ratings from both systems mutually.

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Appendix

a) Hospital de Maudes

b) Camara of de Comercio

c) Museo de Aeronautica

d) Appartamentos de Pl. Espana

e) Instituto Cervantes

f) Cerro San Pedro

g) Segovia

h) Lady Madrid

i) Martonela Goya

j) Cines Golem

Fig. A1: **All ten attractions**

Source: own

Do inconsistent online reviews reduce sales for merchants on the platform? Evidence from China

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Abstract: *Inconsistent online reviews are the norm in online shopping. However, platform merchants often believe that inconsistent online reviews have a negative impact on sales. They delete or hide negative reviews in pursuit of consistent praise. So, do inconsistent online reviews really reduce sales? In view of this, this study explores the impact of inconsistent online reviews on the sales of platform merchants based on the stimuli-organism-response (S-O-R) theory and service remediation theory, as well as its mechanism and boundary conditions. And using 5,487 crawler data and 447 questionnaire data, employing both ordinary least squares (OLS) model for empirical analysis. Moreover, in order to verify the robustness of the empirical results comprehensively and rigorously, four methods of changing the measurement model, adjusting the sample size, changing the data source and transforming the assignment were used to carry out the robustness test. The results show that the inconsistent online reviews have a significant inverted U-shaped effect on the sales of platform merchants. Brand image plays a significant mediating role in the influence of inconsistent online reviews on consumers' purchase intention. And peer response conflict has a significant moderating effect on the impact of online review inconsistency on consumers' purchase intention. Therefore, platform merchants should take a rational and open attitude towards inconsistent online reviews. In addition, platform merchants can adopt intelligent management methods for online reviews, pay attention to the shaping and strengthening of brand image, and pay attention to peer effect through social marketing, so as to maximize the benefits brought by the inconsistency of online reviews and minimize the potential negative impact of the inconsistency.*

Keywords: *Online reviews, platform merchants, brand, response conflict.*

JEL Classification: *M31, L81, M37.*

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Introduction

According to the "Statistical report on China's internet development" released by the China Internet Network Information Center (CNNIC) in 2023, as of December 2022, the scale of online shopping users in China has reached 1.067 billion (CNNIC, 2023), and online shopping has become an important form

of consumption. However, in online shopping, consumers and merchants are physically separated, and consumers cannot touch and feel the goods before the transaction, which leads to the problem of information asymmetry (Liao & Cheung, 2001). This increases consumers' concerns about the quality of goods and distrust of platform merchants, which in turn reduces online spending. Therefore, major e-commerce platforms have launched credit mechanisms that include consumer online reviews and merchant information disclosure to reduce information asymmetry. However, the information disclosed by the merchants may not be true (Jin & Kato, 2006). Online reviews are more driven by consumers' spontaneous sharing, and commercial communication has a lower purpose, which has a stronger influence and persuasiveness on other consumers (Aghakhani et al., 2020). As a result, online reviews can affect the sales of merchants on the platform. Review valence has always been the focus of scholars in the field of online review. Purnawirawan et al. (2015) pointed out that the review valence is the positive and negative affective polarity of online reviews, which can be divided into positive online reviews and negative online reviews. However, whether it is using star ratings to measure the valence of reviews, or using the sentimental tendency of online review texts to measure the valence of reviews, scholars usually focus only on positive online reviews or negative online reviews in the review valence. In the real environment, it is common for the same online review to contain both positive and negative content, the text and rating titer of the same online review are contradictory, and different consumers make inconsistent evaluations or ratings for the same product. Inconsistent online reviews became the norm (He & Bond, 2015). Scholars have also begun to pay attention to the negative impact of inconsistent online reviews on the sales of platform merchants. However, under the influence of Chinese traditional culture, consumers often have the psychology of "extreme things must be reversed." So, do inconsistent online reviews actually reduce sales?

Thinking about the mechanism and boundary conditions of online review inconsistency affecting the sales of platform merchants. In the era of e-commerce, if businesses want to gain more market share, they must focus on brand management. Consumers' brand cognition is a direct factor to stimulate consumers' purchasing behavior (Yang & Liu, 2010). From the perspective of psychological cognition, the brand image reflects consumers' cognition and evaluation of a brand (Hu & Yao, 2021). User-generated content is an important factor affecting the formation of consumer brand cognition (Feng, 2012), and online reviews are an important form of user-generated content. So, will the brand image mediate the impact of inconsistent online reviews on the sales of platform merchants? And in online shopping, consumers are faced with a huge amount of information. Peer response can pre-process redundant information for consumers and become an effective means to reduce consumers' information overload and disadvantage (Wang, 2019). Some studies have pointed out that merchants' response strategies play a moderating role in the impact of inconsistent online reviews on sales (Shan et al., 2022), while compared with ordinary consumers, peers have a more profound impact on individual behaviors (DeLay et al., 2016). So, does peer response conflict moderate the effect of inconsistent online reviews on platform merchant sales?

Current scholars pay more attention to the one-way linear impact of inconsistent online reviews on the sales volume of platform merchants, but do not pay attention to the non-linear impact of inconsistent online reviews on the sales volume of platform merchants. In addition, the researches on the mechanism of the impact of inconsistent online reviews on the sales of platform merchants pay more attention to the mediating role of consumer perception (Huang et al., 2017) and consumer attitude (Shi et al., 2018), but do not pay attention to the mediating role of brand image. As for the moderating effect of inconsistent online reviews on the sales volume of merchant platforms, current scholars pay more attention to the moderating effect of the titer of reviews (Langan et al., 2017) and product types (Huang et al., 2017), but do not consider the importance of peers. To solve the above questions, that is, whether inconsistent online evaluation really reduces sales, whether brand image plays an intermediary role in the impact of inconsistent online evaluation on sales, and whether peer response conflict moderates the impact of inconsistent online evaluation on sales. This study explores the impact of inconsistent online reviews on sales of platform merchants, and

the mediating and moderating role of brand image and peer response conflict. Compared with previous studies, the marginal contribution of this study has the following three points: i) from the perspective of research content, it points out that the inconsistency of online reviews has a significant inverse U-shaped impact on the sales volume of platform merchants; ii) from the perspective of research, based on S-O-R theory and service recovery theory, this paper explores the mediating and moderating effects of brand image and peer response conflict; and iii) from the perspective of research data, empirical analysis is carried out based on crawler data and questionnaire data.

The rest of this study is organized as follows. The first part discusses the theoretical background. The second part introduces variable setting, data source and measurement model setting. The third part reports the empirical results and analyzes them. Finally, the fourth part discusses the research conclusions, management implications, limitations and future research agenda.

1 Theoretical background

In 1913, Watson (1913) proposed S-R (stimulus-response) theoretical model for the first time, pointing out that individual behavior is a response to stimulation. Later, Mehrabian and Russell (1974) added organism to the S-R theoretical model, suggesting that stimuli to an individual can cause an individual to make behavioral responses by influencing internal emotional changes. At present, many scholars have explored consumers' online shopping intention based on S-O-R theory. For example, Zhu et al. (2020) based on S-O-R theory found that perceived information quality and social presence of online comments, as external stimuli, will have an impact on consumer trust and satisfaction, and then affect consumers' purchase intention. Based on the S-O-R theory, Xiong et al. (2024) pointed out that the use of ant forest as an external stimulus would affect consumers' cognitive value (such as knowledge acquisition and utility perception), emotional value (such as satisfaction and pleasure) and social value (such as social interaction and social responsibility), thus affecting consumers' low-carbon consumption behavior. There is a significant positive correlation between consumers' purchase intention and their purchase behavior (Cui et al., 2024), and the sales volume of merchants on the platform is closely related to consumers' purchase behavior. Therefore, based on the S-O-R theory, this study will explore the impact mechanism of inconsistent online reviews on the sales of platform merchants.

According to the S-O-R theory, individual stimuli will affect individual internal emotions and cognition, thus leading to individual behavioral responses. Before opening the "black box" of individual complex behaviors, scholars believe that individual behaviors are stimulated responses. Initially, Baker (1986) divided the external factors of the store environment into three categories based on the offline shopping scene: social factors, design factors and environmental factors. With the rise of online shopping, the traditional ability to appeal to consumers' senses through an infinitely complex combination of various external factors has been limited to the main visual appeal of the screen (Eroglu et al., 2001). Therefore, the external environmental stimulus has expanded from the traditional store environment to network information and network community interaction (Jacoby, 2002). As an important part of network information, online comments will stimulate consumers. Real online shopping is often filled with a large number of positive online reviews, negative online reviews and irrelevant content, and consumers' evaluation of products is formed by the synthesis of multiple online reviews (Du et al., 2021). It can be seen that inconsistent online reviews (S) will have an impact on consumer purchasing behavior (R).

Sun (2012) found that inconsistent online reviews can promote product sales based on real data on Amazon. Tang et al. (2014) found that in the process of online shopping, inconsistent online reviews will convey to consumers the information that product quality is highly likely to be unstable, which will have a negative impact on product sales. However, since culture has an important impact on individual psychology and behavior, consumers who have been in the background of Chinese traditional culture for a long time cannot ignore the influence of Chinese native culture on their psychology and behavior. The culture of the mean is the most representative philosophy in traditional Chinese culture to deal with contradictions, emphasizing a state of just right and too much, and requiring individuals to seek moderation in the continuum of "less than" and "too" (Ma & Cai, 2018). On the one

hand, Tong et al. (2020) pointed out that excessive positive exposure (such as the high-profile publicity of entrepreneurial public welfare) may lead to consumer aversion, especially for those consumer groups with high requirements for moderation, and they may therefore have a negative evaluation of relevant enterprises. Similarly, when online reviews from merchants on the platform are uniformly positive, this highly unified positive feedback may make consumers feel that the merchant is too "loud" and thus influence their purchasing decisions. Research by Zhang et al. (2021) further supported this, pointing out that unanimous praise does not always boost sales growth. On the other hand, according to the "defect effect" theory (Ein-Gar et al., 2012), reviews with negative information are considered more natural and in line with people's general understanding compared to uniformly positive information. Eisend (2006) highlighted the unique role of negative information in enhancing consumers' trust. A small but genuine negative review can act as an "unexpected stimulus," breaking the monotony of pure praise, increasing the richness and credibility of information, thereby stimulating consumers' purchase willingness and promoting sales. However, this positive effect has a boundary condition, that is, the "too much of a good thing" effect (Pierce & Aguinis, 2013). When the ratio of positive and negative reviews is unbalanced, especially when negative reviews increase significantly, the cognitive burden of consumers in processing information increases, leading to decision-making difficulties, and ultimately inhibit purchase behavior and reduce sales. Therefore, in online reviews, moderate negative information can be used as a supplement to positive reviews, which can enhance the authenticity and credibility of reviews, promote consumers' trust and purchase behavior, and thus increase the sales volume of platform merchants. However, when the number of negative reviews is too high, leading to an increase in the overall inconsistency of reviews, this positive effect will gradually diminish or even reverse. Because consumers are dealing with complex, contradictory information, their purchase decision process will be disrupted, and ultimately lead to lower sales. In summary, this study proposes the following hypothesis:

H1: Inconsistent online reviews have an inverted U-shaped impact on the sales volume of platform merchants.

According to the S-O-R theory, the stimuli received by individuals will affect their internal emotions and cognition, and thus lead to their behavioral responses. Therefore, the inconsistency of online comments (S) may affect consumers' purchasing behavior (R) by affecting brand image (O).

First of all, consumers will form the overall cognition of the brand after contact with the brand information, and the brand touch point, as the context for consumers to understand the brand information, will have an important impact on the brand image. With the development of e-commerce, online brand touch points can be divided into three categories: the brand information of the enterprise itself, the brand comments of social media and the experience of consumers' participation in brand image construction. Compared with the brand information of enterprises themselves, consumers trust brand comments on social media more (Zhang, 2013). Therefore, online reviews become an important touchpoint for consumers to obtain brand information. Some scholars have shown that negative online comments can significantly negatively affect brand image (Bambauer-Sachse & Mangold, 2011). However, for consumers in the context of Chinese traditional culture, due to excessive emphasis on mediocrity, individual behavior traits such as compromise and fear have evolved over thousands of years (Xie, 2024). Consumers have a certain tolerance for merchant mistakes. If consumers believe that the errors described in negative online reviews are insignificant, it will not affect their purchase behavior of the platform merchants' products, but will enhance the authenticity of the merchants' online reviews. Therefore, when a small number of negative online reviews appear in the favorable reviews, it will increase consumers' trust in the brand, and thus improve consumers' overall perception of the brand. However, once the degree of inconsistency of online reviews exceeds the tolerance range of consumers, the higher the degree of inconsistency of online reviews, the more consumers can perceive the uncertainty of product quality, thus forming a negative perception of the brand. In summary, inconsistent online reviews have a significant inverted U-shaped impact on brand image.

Secondly, consumers' brand cognition is a direct factor that stimulates consumers' purchasing behavior (Yang & Liu, 2010).

Brand image, as consumers' overall cognition of the brand, will affect consumers' purchasing behavior. For example, Li and Liu (2018) pointed out that brand image has a significant positive effect on enhancing consumer purchasing behavior. Tariq et al. (2017) pointed out that brand image plays a significant mediating role in the influence of e-word-of-mouth on consumer purchasing behavior, and online reviews are a new form of e-word-of-mouth. Rao et al. (2021) pointed out that both functional brand image and hedonic brand image will mediate the influence of online reviews on consumers' purchase intention to some extent. There is a significant positive correlation between consumers' purchase intention and their purchase behavior (Cui et al., 2024), and the sales volume of merchants on the platform is closely related to consumers' purchase behavior. In summary, this study proposes the following hypothesis:

H2: Brand image plays an intermediary role in the process of inconsistent online reviews affecting the sales of platform merchants.

H2a: Inconsistent online reviews have an inverted U-shaped impact on brand image.

H2b: Brand image has a significant positive impact on the sales of platform merchants.

In the field of marketing research, Chou (2018) pointed out that service recovery refers to the measures taken by merchants to improve consumers' willingness and satisfaction when the products or services provided by merchants cause losses to consumers or fail to achieve the expected purpose of consumers. Bai et al. (2024) believed that service recovery is the follow-up action taken by merchants to solve service failure events and consumers' complaints when the products or services provided by merchants do not meet consumers' expectations. It can be seen that service recovery can summarize a series of positive remedial measures taken by merchants after service mistakes to improve consumers' satisfaction and willingness.

At present, scholars have conducted extensive research on the service recovery behavior taken by merchants after service mistakes. For example, Xu et al. (2022) pointed out that in the process (outcome) type service failure scenario, compared with "material remedy before spiritual remedy," the remedial strategy order of "spiritual remedy before material remedy" respectively has a higher (lower) impact on customers' intention to participate in service remedy and customers' perception of enterprise support. However, the change in consumers' satisfaction and willingness depends not only on the remedy strategy, but also on the remedy agent. For example, Jiang et al. (2024) found that consumers' satisfaction will be higher because humans can provide more sincere services than service robots. Han et al. (2022) found that responder identity had no significant effect on the perception of distributive justice and interpersonal justice. Therefore, this study will explore the moderating effect of peer response conflict based on service recovery theory.

Based on the theory of service recovery, after service failure, merchants will take a series of measures to improve the satisfaction and willingness of consumers. In online shopping, consumers often talk about their unpleasant experience of a merchant's products or services through negative online reviews. However, merchants cannot explain to consumers in person, so responding to negative online reviews has become an effective means of service recovery for merchants. Liang's (2016) research showed that consumers' doubts about the authenticity of corporate information will change with different communication situations. Therefore, consumers' perception of inconsistent online reviews will vary depending on the context in which merchants and consumers communicate. As peer responses are often closer to the language and way of thinking of consumers and are more easily accepted and understood by consumers, peer responses will have a more profound impact on individual behaviors (Delay et al., 2016). Then, in the context of peer response conflict, consumers' perception of inconsistent online reviews will change.

First, conflicting responses from merchants to negative online reviews are essentially positive messages. When high-quality negative online reviews and merchant responses exist at the same time, consumers tend to take the merchant's high-quality responses as the dominant information in the information processing process (Shan et al., 2022). As a result, when peers make high-quality responses to negative online reviews, consumers pay more attention to the content of the peer responses. Although negative online reviews convey negative information about the lack of integrity and other aspects of the business,

timely responses from peers can attract consumers' attention to the positive content of peer responses. The peers' responses mitigate the negative impact of negative online reviews and enhance the persuasive power of positive online reviews. Therefore, peer response conflict has a moderating effect on the inverse U-shaped relationship between online review inconsistency and platform merchant sales.

Secondly, peers are an important influencing force and reference group in the process of consumer socialization. Once consumers believe that the group recognizes a brand, they will be less skeptical of the brand (Liang, 2016). Therefore, peers' positive responses to negative online reviews in the context of inconsistent online reviews can gain consumers' trust through their peer status, thus enhancing consumers' overall perception of the brand. In addition, peer response conflict means that peers respond positively to the content of negative online comments, and the response content is more detailed, which can reduce the uncertainty risk of inconsistent online comments. Therefore, peer response conflict has a moderating effect on the inverse U-shaped relationship between online comment inconsistency and brand image. In summary, this study proposes the following hypothesis:

H3: Peer response conflict plays a moderating role in the impact of inconsistent online reviews on the sales of platform merchants.

H3a: Peer response conflict has a moderating effect on the inverse U-shaped relationship between online review inconsistency and platform merchant sales.

H3b: Peer response conflict has a moderating effect on the inverse U-shaped relationship between online review inconsistency and brand image.

Based on the above assumptions, this study draws the conceptual model diagram shown in Fig. 1.

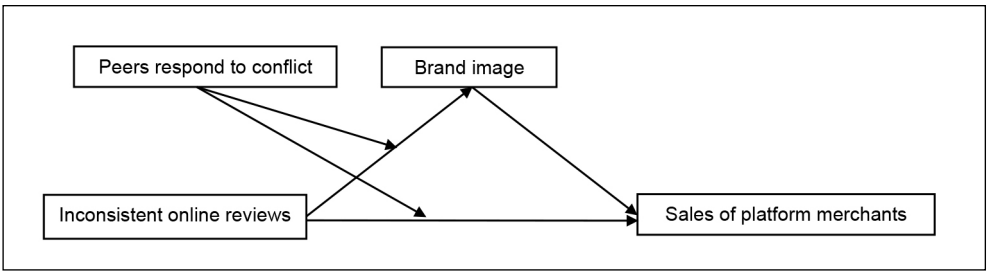

Fig. 1: Conceptual model

Source: own

2 Research methodology

2.1 Measures

In this study, the study variables are measured based on crawler data and questionnaire data. After the reliability and validity test of the scale of each variable, SPSS 26.0 is used for factor analysis, dimensionality reduction of the study variable was processed, and the factor score obtained by regression method is used as its final measurement value.

Dependent variable: sales of platform merchants. Commodity sales data are confidential data of online shopping platforms and cannot be directly obtained. Scholars usually use the number and sales of online comments rank two surrogate variables to measure product sales. In addition, since the sales ranking is opposite to the sales volume, the first ranked product has the highest sales volume, so this study uses the inverse of the sales ranking to measure the sales volume of the platform merchants. Consumers' purchase intention has a positive impact on purchasing behavior (Cui et al., 2024), and the sales volume of merchants on the platform is closely related to consumers' purchase behavior. Therefore, this study uses consumers' purchase intention to measure the sales volume of merchants on

the platform. Based on the questionnaire data, consumers' purchase intention is measured by referring to the five-item scale developed by Dodds et al. (1991).

Independent variable: inconsistent online reviews. Based on crawler data, the probability value of online comments belonging to the positive category calculated by python language tools and Baidu intelligent cloud natural language processing API is used as the text sentiment value of online comments, and the variance of text sentiment value within a single month is used to measure the inconsistency of online comments (because the JD platform does not display consumers' ratings on products). Moreover, the text analysis of the same online review containing both positive and negative information is complicated, so the inconsistency of online reviews in this part only focuses on the differences between the text of reviews of different consumers for the same product. Based on the questionnaire data, the measurement of inconsistent online comments is mainly based on the scale developed by Shi et al. (2018), and appropriately modified in combination with the research of Baek (2012) and Schlosser (2011).

Intermediate variable: brand image. Based on the questionnaire data, the brand image is measured using the nine-item scale developed by Aaker (1991). The six-item scale with two dimensions of product image and user image is selected.

Moderating variable: peer response conflict. Based on the questionnaire data, peer response conflict is measured mainly by referring to the relevant research of Wang's (2019) zagging theory, and the peer response conflict scale is designed.

Control variables. The control variables of this study include three aspects: individual characteristics, commodity characteristics and store characteristics. The controlling variables of individual characteristics include sex, age, edu and monthly disposable income. The controlling variables of store characteristics include price, price satisfaction, praise rate, and number of reviews. The control variables of store characteristics include JD self management.

2.2 Data collection and processing

Crawling data. This study uses octopus harvester to capture the top 100 pages of laptop data of JD by sales rank on October 1, 2023, and finally captured 5,846 items and 2,972,918 online reviews, and screened 517,903 online reviews from September 1, 2023 to September 30, 2023. The data are processed as follows: i) delete the default online review data of the system; ii) delete the online review data with repeated content in the same product; and iii) delete online comment data with comments of 3 words or less. After processing, the final sample size was 5,487.

Questionnaire data. After the preliminary design of the questionnaire scale is completed, 42 questionnaires are first issued for a small range of pre-research, and 33 valid questionnaires are obtained. The results of reliability test show that the scale of research variables has good reliability, and the results of validity test show that the aggregate validity of brand image is poor. Scholar Gorsuch (1983) pointed out that if factor analysis is carried out, the total sample size should not be less than 100. Therefore, a total of 628 questionnaires are sent out in the formal investigation of this study. After deleting the sample data with answer time less than 90 seconds and obvious logic errors, 447 valid questionnaires are obtained, with an effective recovery rate of 71.18%.

Reliability test. According to previous studies, $0.60 \leq$ Cronbach's $\alpha < 0.80$ indicates that the scale is reliable, $0.80 \leq$ Cronbach's $\alpha < 1.00$ indicates that the scale is highly reliable (Kurhan et al., 2018; Raharjanti et al., 2022).

Tab. 1: Reliability test results of the scale

Variable	Item quantity	Cronbach's α
Inconsistent online reviews	4	0.613
Brand image	6	0.786
Peers respond to conflict	7	0.831
Purchase intention	5	0.796

Source: own

The results of the reliability test for this study are presented in Tab. 1, demonstrating that the scale has reliability.

Distinguishing validity. The discriminative validity test results of this study are shown in Tab. 2. The results show that the four-factor model has the best fit, and meets the empirical criteria of 1 < 2/df < 2, RMSEA < 0.05, CFI > 0.9 and TLI > 0.9, so the variables have good discriminative validity.

Tab. 2: Results of discriminative validity test of the scale

Model	χ^2	df	χ^2/df	RMSEA	CFI	TLI
Four-factor model (*RI*, *BI*, *PC*, *SL*)	333.499	203	1.643	0.038	0.951	0.944
Three-factor model (*RI*, *BI* + *PC*, *SL*)	898.667	207	4.341	0.087	0.738	0.707
Two-factor model (*RI* + *BI* + *PC*, *SL*)	935.007	208	4.495	0.089	0.724	0.694
Single factor model (*RI* + *BI* + *PC* + *SL*)	1,250.612	209	5.984	0.106	0.605	0.564

Note: *RI* – inconsistent online reviews; *BI* – brand image; *PC* – peers respond to conflict; *SL* – the sales of platform merchants.

Source: own

2.3 Model setting

Reference regression. The explained variable is the consumer's purchase intention, which is a continuous variable. Therefore, the OLS model is used for baseline regression in this study. The model settings are as follows:

$$SL = \alpha_1 + \beta_1 RI_i + \beta_2 RI_i^2 + \gamma_1 Z_i + \delta_i \quad (1)$$

where: *SL* – sales by merchants on the platform, RI_i – online reviews are inconsistent; RI_i^2 – the square term of *RI*; β_1 – the influence coefficient of RI_i on online review inconsistency on the sales volume of platform merchants; β_2 – the influence coefficient of RI_i^2 on the sales volume of platform merchants. According to the one variable quadratic function, if $\beta_2 > 0$, the inconsistency of online reviews has a significant U-shaped effect on the sales volume of platform merchants. If $\beta_2 < 0$, the inconsistency of online reviews has a significant inverted U-shaped effect on the sales volume of platform merchants. Z_i represents the control variables. Specifically, according to the availability of data, when the data source is a crawler, the control variables include price, favorable rate, number of reviews and JD self-support. When the data source was a questionnaire, the controlling variables included sex, age, edu, monthly disposable income, and price satisfaction. δ_i is the random disturbance term.

Mediation effect test. According to the test method proposed by Baron and Kenny (1986), the mediating role of brand image in the impact of inconsistent online reviews on the sales of platform merchants is verified, and the following model is constructed:

$$SL = \alpha_3 + \beta_5 RI_i + \beta_6 RI_i^2 + \gamma_3 Z_i + \delta_i \quad (2)$$

$$BI = \alpha_4 + \beta_7 RI_i + \beta_8 RI_i^2 + \gamma_4 Z_i + \delta_i \quad (3)$$

$$SL = \alpha_5 + \beta_9 RI_i + \beta_{10} RI_i^2 + b_1 BI_i + \\ + \gamma_5 Z_i + \delta_i \quad (4)$$

where: *BI* – brand image; β_7, β_8, β_9 and β_{10} – the impact coefficient of online comment inconsistency and its square term on brand image, and the impact coefficient of online comment inconsistency and its square term on sales of platform merchants after adding brand image variables, respectively; b_1 – the influence coefficient of brand image on the sales volume of platform merchants.

Adjustment effect test. According to the test method of Edwards and Lambert (2007), the moderating effect of peer response conflict is significant by judging whether the interaction term between the moderating variable and the square term of the independent variable is significant, and the following model is constructed:

$$SL = \alpha_6 + \beta_{11} RI_i + \beta_{12} RI_i^2 + \theta_1 PC_i + \\ + k_1 RI_i * PC_i + k_2 RI_i^2 * PC_i + \gamma_6 Z_i + \delta_i \quad (5)$$

$$BI = \alpha_7 + \beta_{13} RI_i + \beta_{14} RI_i^2 + \theta_2 PC_i + \\ + k_3 RI_i * PC_i + k_4 RI_i^2 * PC_i + \gamma_7 Z_i + \delta_i \quad (6)$$

where: *PC* – peers respond to conflict; k_1, k_2, k_3 and k_4 – the influence coefficients of online comment inconsistency, square term and peer response conflict interaction term on the sales volume and brand image of platform merchants, respectively; θ_1 and θ_2 – the influence coefficient of peer response conflict on sales and brand image of platform merchants.

3 Results and discussion

3.1 Baseline regression

Tab. 3 shows the results of baseline regression. When the data source is crawler data, columns 1–3 are the benchmark regression results with only core explanatory variables and control for commodity characteristics (price, favorable rate, number of reviews) and store characteristics (JD self-support). When the data source is questionnaire data, columns 1–3 are the benchmark regression results with only core explanatory variables, controlling for individual characteristics (sex, age, edu, monthly disposable income) and controlling for commodity characteristics (price satisfaction), respectively. The results show that regardless of whether the individual characteristics, product characteristics and store characteristics are controlled, the influence coefficient of inconsistent online reviews on the sales volume of platform merchants is significantly positive, and the influence coefficient of the square term of inconsistent online reviews on the sales volume of platform merchants is significantly negative. According

Tab. 3: Baseline regression results

Data source	Variable	(1)		(2)		(3)	
		SL		*SL*		*SL*	
Crawling data	*RI*	0.049***	(0.012)	0.038***	(0.012)	0.031***	(0.012)
	RI²	−0.209***	(0.068)	−0.174**	(0.067)	−0.141**	(0.068)
	Price	–		0.001	(0.001)	0.000	(0.001)
	Favorable rate	–		−0.008	(0.000)	0.003	(0.008)
	Number of reviews	–		0.001***		0.001***	(0.000)
	JD self-support	–		–		0.003***	(0.001)
	Cons_	0.001	(0.000)	0.007	(0.008)	−0.003	(0.008)
Questionnaire data	*RI*	0.129**	(0.050)	0.127**	(0.050)	0.116**	(0.048)
	*RI * RI*	−0.140***	(0.020)	−0.135***	(0.020)	−0.109***	(0.020)
	Sex	–		−0.142	(0.087)	−0.120	(0.084)
	Age	–		0.135	(0.085)	0.108	(0.082)
	Edu	–		−0.006	(0.064)	0.021	(0.062)
	Monthly disposable income	–		0.072*	(0.038)	0.051	(0.037)
	Price satisfaction	–		–		0.314***	(0.054)
	Cons_	0.139***	(0.047)	−0.160	(0.283)	−1.417***	(0.348)

Note: *RI* – inconsistent online reviews; *SL* – the sales of platform merchants; ***, **, and * represent significant at 1, 5, and 10% confidence levels, respectively (two-tail test); the standard error of regression results in parentheses.

Source: own

to the basic properties of the one-variable quadratic function, if the coefficient of the square term is less than 0, the parabola opens downward, which means that with the increase of x, the y value will first increase (before reaching the vertex) and then decrease (after passing the vertex), that is, the inverted U-shaped curve. Therefore, inconsistent online reviews have a significant inverted U-shaped effect on the sales of platform merchants. *H1* is verified.

3.2 Robustness test

In this study, four methods are used to verify the robustness of the model: changing the measurement model, changing the sample size, changing the data source and changing the assignment method. One is to replace the measurement model. For crawler data, Tobit regression model is used. Breakpoint regression model was used for questionnaire data. The second is to change the sample size. For crawler data, the sample data whose online comments are inconsistent with 0 is deleted. For the questionnaire data, the sample data whose answer time is less than 120 seconds is deleted. The third is to change the data source. For crawler data, octopus harvester is used to capture the data of JD's top 100 suitcases (experiential goods) according to the sales ranking on October 1, 2023, and 4,925 goods and 244,849 online comments are obtained, with a final sample size of 1,042. The fourth is to change the method of assignment. For the questionnaire data, each variable is re-measured by calculating the average value of each variable scale item. It can be seen from the results in Tab. 4 that the robustness of the estimated results in this study is strong, and the inconsistency of online reviews has a significant inverted U-shaped impact on the sales volume of platform merchants.

Tab. 4: Robustness test results

Data source	Variable	Change the measurement model	Change the sample size	Change the data source	Change the assignment mode
		Tobit model/ breakpoint regression model	*SL*	*SL*	*SL*
Crawling data	*RI*	0.031*** (0.012)	0.032* (0.013)	0.084 (0.052)	–
	RI^2	−0.141** (0.068)	−0.143* (0.070)	−0.632* (0.260)	–
	Control variable	Yes	Yes	Yes	–
Questionnaire data	RI_{low}	0.396*** (0.059)	–	–	–
	RI_{high}	−0.421** (0.191)	–	–	–
	RI	–	0.113** (0.054)	–	1.660*** (0.252)
	RI^2	–	−0.129*** (0.021)	–	−0.201*** (0.035)
	Control variable	Yes	Yes	Yes	Yes

Source: own

3.3 Intermediate effect test

As can be seen from Tab. 5, the influence coefficient of inconsistent online comments on brand image is significantly positive, and the influence coefficient of the square term of inconsistent online comments on brand image is significantly negative, indicating that inconsistent online comments have a significant inverted U-shaped influence on brand image. Moreover, after adding the variable of brand image, the impact of inconsistent online reviews on the sales of merchants on the platform still presents an inverted U shape, and brand image has a significant positive impact on the sales of platform merchants. So, brand image plays a significant intermediary role. In summary, *H2* is verified.

Tab. 5: Results of mediation effect test

Variable	*SL*		*BI*		*SL*	
RI	0.116**	(0.048)	0.122**	(0.050)	0.080*	(0.046)
RI²	−0.109***	(0.020)	−0.116***	(0.020)	−0.075***	(0.019)
BI	–		–		0.297***	(0.044)
Control variable	Yes		Yes		Yes	
Cons_	−1.417***	(0.348)	−0.687*	(0.362)	−1.212***	(0.333)

Note: *RI* – inconsistent online reviews; *BI* – brand image; *SL* – the sales of platform merchants; ***, **, and * represent significant at 1, 5, and 10% confidence levels, respectively (two-tail test); the standard error of regression results in parentheses.

Source: own

3.4 Adjustment effect test

According to the study of Edwards and Lambert (2007), if the interaction between the square term of the explanatory variable and the regulating variable has a significant influence on the explained variable, it indicates that the regulating effect is significant. It can be seen from Tab. 6 that the square term of online comment inconsistency and the interaction term of peer response conflict have a significant positive impact on brand image. Therefore, under the moderating effect of peer response conflict, the inverted U-shaped effect of online comment inconsistency on brand image becomes smooth, that is, the increase of peer response conflict strengthens the inhibiting effect before the curve inflection point and the promoting effect after the inflection point. This may be because when there are inconsistent opinions in online reviews, peer response conflicts may help consumers form a more comprehensive and objective brand perception by providing interpretation or refutation from different perspectives, thus balancing the conflicts between different opinions to some extent. *H3b* is verified. The square term of inconsistent online reviews and the interaction term of conflicting peer responses have no significant impact on the sales of platform merchants, so *H3a* is not verified. In summary, *H3* is partially verified.

Conclusions

Based on S-O-R theory and service recovery theory, this study constructs a conceptual

Tab. 6: Test results of adjustment effect

Variable	*BI*		*SL*	
RI	0.081	(0.051)	0.092*	(0.050)
RI²	−0.043	(0.033)	−0.057	(0.032)
PC	0.090*	(0.051)	0.056	(0.050)
RI * PC	−0.005	(0.052)	−0.037	(0.050)
RI² * PC	0.024*	(0.013)	−0.101	(0.012)
Control variable	Yes		Yes	
Cons_	−0.562	(0.361)	−1.335***	(0.350)

Note: *RI* – inconsistent online reviews; *BI* – brand image; *PC* – peers respond to conflict; *SL* – the sales of platform merchants; ***, **, and * represent significant at 1, 5, and 10% confidence levels, respectively (two-tail test); the standard error of regression results in parentheses.

Source: own

model, and conducts empirical analysis based on 5,487 crawler data and 447 questionnaire data, and draws the following conclusions: first, this research reveals the subtle but significant inverted U-shaped influence of online review inconsistency on the sales of platform merchants. This finding challenges the conventional wisdom that a market environment dominated by positive reviews inevitably leads to sales growth. In fact, when online reviews are highly consistent and positive, this "flawless" appearance may trigger consumers' vigilance. They believe that these reviews may not be true enough or there are suspicions of manipulation, and thus reduce the willingness to buy, leading to a decline in sales. On the contrary, when a few negative reviews are interspersed with many positive reviews. They are like "flavoring agents," adding a sense of reality to the evaluation system, stimulating consumers' curiosity and desire to explore, and promoting sales. However, once the number or content of negative reviews exceeds the psychological tolerance threshold of consumers, forming a strong evaluation inconsistency, consumers will be trapped in decision-making difficulties, resulting in cognitive conflicts, and finally choose to avoid buying, and sales will decline. Secondly, this study deeply analyzes the key mediating role of brand image in this complex influence mechanism. Brand image is deeply affected by the inconsistency of online comments. When the evaluation inconsistency is at a moderate level, the existence of a small number of negative comments enhances the credibility and attractiveness of the brand image, and thus promotes the growth of sales. However, as the evaluation inconsistency intensifies, the accumulation of negative comments gradually erodes the positive image of the brand image, and ultimately adversely affecting sales. This process fully demonstrates the important role of brand image in regulating the relationship between online reviews and sales. Finally, this study explores the unique role of peer response conflict in mitigating the U-shaped impact of online review inconsistencies on brand image and sales. Peer response conflict does not directly change the impact of online comment inconsistency on the sales of platform merchants. But it adjusts and smoothen the inverted U-shaped relationship between online comment inconsistency and brand image. Specifically, when peers respond positively to negative online reviews, their positive attitudes can effectively reduce consumers' fear of negative reviews and improve the persuasiveness. This peer effect not only enhances consumers' positive cognition and trust in the brand. But it also reduces the uncertainty risk and decision conflict caused by evaluation inconsistency, thus alleviating the negative impact of negative reviews on sales to a certain extent.

The conclusions of this study provide valuable management implications for platform merchants on how to improve their sales by managing online reviews. First of all, platform merchants should conduct intelligent management of online reviews. Platform merchants should establish a systematic customer feedback mechanism, not only limited to immediate contact after purchase, but also collect opinions regularly during the product life cycle. Encourage consumers to share truthful, multi-dimensional feedback, including feedback that may seem negative, by designing diverse incentives, such as points redemption, membership privileges, etc. This open and inclusive attitude can enhance the integrity of the brand and attract more potential customers. And using big data, intelligent analysis of massive reviews can identify valuable negative reviews and repetitive, meaningless positive reviews. Reasonable control of the display ratio, both to show the real face, but also to avoid excessive negative caused by consumer panic. Secondly, platform merchants should carry out brand building and strengthening. Combine online reviews to build brand stories that demonstrate brand values, corporate culture and social responsibility. Through the brand image, enhance consumer loyalty to the brand, even in the face of a small number of negative reviews, but also maintain a stable sales situation. Moreover, for the negative comments beyond the tolerance range, businesses should respond quickly and take positive measures. Through timely remedial measures and follow-up services, demonstrate brand responsibility and problem-solving ability to effectively repair brand image. Finally, platform merchants should pay attention to peer effect and conduct social marketing. Hire opinion leaders or industry experts to engage as "peers" in responding to and interacting with online reviews. Their professional insights and positive attitude can significantly enhance the credibility of reviews and reduce consumer doubts. At the same time, these experts can guide the conversation and promote the spread

of positive word of mouth. Moreover, brand communities can be built to encourage communication and sharing between consumers and between consumers and brands. Enhance user stickiness through community activities, exclusive benefits and other ways. In the community, responses to negative comments can be timelier, thus effectively mitigating their negative impact.

Despite the implications, our study has some limitations. Firstly, there may be cultural differences between the Chinese market and other markets, which may affect the interpretation of data and the universality of the conclusions. Therefore, it is necessary to conduct heterogeneity research on related issues. Secondly, although different types of online review inconsistencies are considered in the scale measurement, there is no comparative study on the impact of different types of online review inconsistencies on the sales of platform merchants. Moreover, this study did not consider the difference in the impact of inconsistent online reviews on the sales of platform merchants under different backgrounds. Therefore, in the future research, scholars can discuss and study from the above two aspects.

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Appendix

Tab. A1: Variable measurement scale

Variable	Item	Completely disagree → completely agree				
Inconsistent online reviews	Sometimes both positive and negative content can be included in the same comment	1	2	3	4	5
	Reviews from different consumers sometimes contradict each other	1	2	3	4	5
	There are sometimes large differences in the rating of the product in the reviews of different consumers	1	2	3	4	5
	Sometimes the content and the rating in the same comment do not match	1	2	3	4	5
Brand image	The quality of this brand is good	1	2	3	4	5
	The brand is excellent value for money	1	2	3	4	5
	There are reasons to buy products from that brand over similar products from other brands	1	2	3	4	5
	The brand has a distinct personality	1	2	3	4	5
	The brand can provide me with symbolic or emotional value	1	2	3	4	5
	I know exactly what kind of people are the consumers of this brand	1	2	3	4	5
Peers respond to conflict	Responses sometimes point out that negative reviews are of low informational value in terms of, e.g., product features, and parameters	1	2	3	4	5
	Responses sometimes point out that negative reviews misjudge the authenticity of the product	1	2	3	4	5
	Responses sometimes point out that negative reviews are inaccurate about product design and workmanship	1	2	3	4	5
	Responses sometimes point out that the negative review publisher misstated the price of the product	1	2	3	4	5
	Responses sometimes point out that negative review publishers are unaware of price increases and price reductions	1	2	3	4	5
	Responses sometimes point out that negative comments are “waterlogged” or “waterlogged” posts that are untrue	1	2	3	4	5
	Responses sometimes point to negative reviews as malicious insults or fabrications by the review publisher	1	2	3	4	5
Consumer purchase intention	I have a good chance of buying this product	1	2	3	4	5
	At the same price, I would consider buying this product	1	2	3	4	5
	There is a good chance that I will consider buying this product	1	2	3	4	5
	I would like to buy this product	1	2	3	4	5
	If I need to buy similar products, I will choose this product as my first choice	1	2	3	4	5

Source: own

Charting the path to consumer satisfaction: An innovative investigation into fresh e-commerce through text mining and spatiotemporal analysis

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Abstract: *The rapid expansion of fresh food e-commerce introduces significant challenges in logistics service quality due to the perishability of products. However, the effects of these challenges on customer satisfaction, particularly across different regions and seasons, have been insufficiently explored. This study addresses this gap by analyzing Jingdong (JD)'s e-commerce reviews using latent dirichlet allocation (LDA) topic models to extract dimensions of logistics service quality, combined with sentiment analysis to evaluate both service quality and customer satisfaction. The research investigates how logistics service quality influences satisfaction, accounting for spatial and temporal variations. Key findings reveal that logistics attributes such as quality assurance, reliability, and convenience play a crucial role in shaping customer satisfaction, with their relative importance differing by region and season. For example, convenience is more critical in remote areas, whereas affluent regions place greater emphasis on empathy. Additionally, higher temperatures amplify the impact of logistics attributes. Repeat customers tend to demand higher service quality compared to first-time buyers. These insights provide actionable recommendations for e-commerce firms seeking to optimize logistics services and enhance their competitiveness.*

Keywords: *Fresh food e-commerce, service quality, online reviews, text mining, customer satisfaction.*

JEL Classification: *M11, P36, Q21.*

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Introduction

With the e-commerce industry's evolution and cold chain logistics technology's ongoing advancement, fresh food e-commerce has garnered increasing consumer interest due to its convenience, efficiency, and diverse offerings. It has emerged as a significant component of China's burgeoning new economy and

industry, attracting scholarly attention and serving as a focal point of discussion in the post-epidemic era (Beckers et al., 2021; Han et al., 2022; Mortimer et al., 2024; Shi & Li, 2023; Tsang et al., 2021). The perishable and delicate nature of fresh products underscores the critical role of service quality in ensuring customer satisfaction within fresh food e-commerce (Lin et al., 2021; Liu et al., 2023; Ma et al., 2021). Factors such as inadequate packaging during distribution, subpar storage conditions, delayed deliveries, and improper handling by staff can lead to quality deterioration and consumer discontent. Consequently, the fresh food e-commerce sector imposes higher demands compared to other industries in terms of standardized logistics and distribution management, infrastructure, and workforce quality (Palese & Usai, 2018). Furthermore, China's vast territory and regional economic disparities, coupled with varying geographical conditions, pose challenges to fresh food logistics services, alongside diverse consumer demands and expectations (Haley, 2002; Ji et al., 2024). Hence, fresh food e-commerce enterprises must comprehend and adapt to these disparities to enhance service quality effectively.

In the past, prominent e-commerce platforms refrained from disclosing users' internet protocol (IP) information to uphold consumer privacy standards, resulting in limited spatial exploration within e-commerce services. The exploration of geography and e-commerce is mostly based on survey data (Qian & Chen, 2023; Zhao et al., 2019). However, a notable shift occurred in March 2023, driven by initiatives to foster an environmentally conscious online environment. The JD e-commerce platform commenced displaying IP addresses of reviewing users on product review pages, in compliance with regulations issued by the Cyberspace Administration of China. This initiative lays the groundwork for extensive research endeavors, enabling scholars to utilize review data to investigate regional disparities.

On the other hand, seasonal variations pose distinct challenges for logistics services in the fresh food e-commerce domain, primarily due to the perishability of fresh products and the stringent requirements for storage temperature in different seasons (Steinker et al., 2017; Yin et al., 2023). Consequently, examining the influence of temporal fluctuations on consumers' logistics service demands through a seasonal lens holds significant implications. Such analysis facilitates the adoption of tailored logistics strategies by fresh food e-commerce enterprises, aligning with seasonal variations to enhance overall service quality and responsiveness.

This paper mainly contributes to the exploration of the impacts and fluctuations induced by varying transportation distances, economic disparities, and seasonal variations on consumer demand within the fresh food e-commerce sector. It aims to offer tailored logistics service recommendations to fresh food e-commerce enterprises, thereby augmenting customer satisfaction levels. Specifically, we select JD Fresh as an example, employing an analysis of online comments to dissect the intricacies of fresh food e-commerce service quality from the vantage point of consumer demand. Furthermore, leveraging IP address and date information extracted from comments, we delve into the distinct demand characteristics across different regions and seasons, thus furnishing pertinent suggestions for fresh food e-commerce enterprises to refine their logistics services in a targeted manner. This approach aims to bolster their capacity to efficiently address consumer needs and bolster their competitiveness within the marketplace.

The remainder of this paper is organized as follows: Section 1 presents the research background, reviewing existing research on fresh e-commerce, customer satisfaction and corresponding methodologies. Section 2 explains the whole process and proposed approach. Section 3 empirically analyzes the impact of fresh food e-commerce service quality on customer satisfaction and explores the heterogeneity of new and existing customers based on different number of purchases. The final section summarizes conclusions, implications and limitations for this work.

1 Theoretical background

1.1 Fresh food e-commerce

The fresh food e-commerce sector has witnessed over a decade of evolution, mainly focusing on operational models, supply chain management, and logistics and distribution.

In terms of operational models, Tontini and Silen (2017) used the "punishment-reward" contrast analysis to argue that safety, fault recovery, speed, communication, flexibility, reliability, and friendliness constitute the framework

of the logistics service quality model. Meanwhile, Yang et al. (2022) investigated factors shaping satisfaction in fresh produce e-commerce, employing latent dirichlet allocation (LDA) to validate the reassuring influence of e-commerce services amidst the COVID-19.

In terms of supply chain management, Song and He (2018) examined optimal decision-making in centralized and decentralized channels using a three-layer FAP supply chain game theory model encompassing fresh agricultural products e-commerce firms, community convenience stores, and third-party logistics providers. Yang and Tang (2019) conducted a comparative analysis of various sales modes within the fresh produce supply chain using the supplier-retailer Stackelberg model.

In terms of logistics and distribution, Wang et al. (2022) formulated a mathematical model aimed at minimizing time-window penalty costs and mileage segment-based distribution expenses, thereby enhancing distribution efficiency and reducing operational costs for fresh produce sales enterprises. Yang et al. (2024) employed perceptual engineering to emotionally design fresh e-commerce logistics services, catering to the implicit needs of fresh produce consumers. Zahran (2024) tackled the time dependent vehicle routing problem (TDVRP) problem in fresh e-commerce delivery, proposing a method that can effectively avoid the time period of traffic congestion, reduce the total distribution cost, and promote energy saving and emission reduction.

The above studies have made bottleneck breakthroughs for the difficult problems of fresh food e-commerce, while they are largely based on different kinds of operations or game models, and lack of empirical studies based on the consumer perspective that are closer to reality. Although there are a handful of studies on the online shopping scenarios, they have ignored the spatial and temporal perspectives, which do matter for perishable fresh products.

1.2 Service quality

Research on service quality often centers on evaluating it, frequently employing the service quality (SERVQUAL) model (Parasuraman et al., 1998). However, Mentzer et al. (1999) argued that the traditional SERVQUAL model, designed for process-oriented services, may not fully apply to result-oriented logistics services. Thus, they propose the LSQ model, adapting SERVQUAL to suit logistics service characteristics.

Numerous scholars have conducted empirical studies based on the SERVQUAL and LSQ models. Zhang and Hou (2013) used the Cronbach-alpha methodology to gauge the gap between customer expectations and perceptions, examining SERVQUAL dimensions' impact on supply chain service quality. Limbourg et al. (2016) utilized the SERVQUAL scale to assess service quality in logistics companies, identifying deficiencies in transportation and claims handling, necessitating greater attention. Classical service quality theories, while foundational, may not universally apply, prompting scholars to adapt and propose tailored evaluation methods. Yang et al. (2024) gleaned consumer insights from fresh food reviews, constructing service quality indicators for fresh food e-commerce. Yang and Huang (2024) verified that empathy strategies in service quality can awaken consumer forgiveness from service remediation.

These studies provide a theoretical rationale for fine-tuning on the classical service quality models and we will explore the service insights with grounded method based on online reviews.

1.3 Customer satisfaction and text mining based on online reviews

Customer satisfaction is recognized as a key to business performance as well as sustainable growth. Scholars have quested potential influences on the impact of satisfaction from various perspectives and have confirmed its importance. Anderson et al. (1994) underscored the direct impact of service quality on customer satisfaction, indicating its implications for firm performance and profitability. Lim et al. (2021) discovered through text mining and regression analysis that fresh food consumers care about speed, price, cold chain transportation, packaging, quality, error handling, service staff, and logistics information. Gao (2021) analyzed fresh food e-commerce logistics, emphasizing factors enhancing service satisfaction and proposing risk management strategies. However, with the development of the Internet and big data, it is difficult for merchants and researchers to use traditional survey methods such as questionnaires and interviews. Text mining techniques based on online reviews have advantages over traditional survey methods in terms of data volume, objective results, and

lower acquisition costs. Thus, they are used by scholars for customer satisfaction. Calheiros et al. (2017) used the LDA model to classify hotel consumer emotions, and found that hotel cuisine can lead to general positive emotions, while hospitality not only brings general positive attitudes but also strong positive attitudes. Wang et al. (2021) utilized TF-IDF and *K*-means algorithms to extract and cluster keywords from hotel reviews, identifying 10 satisfaction factors. Yang et al. (2024) integrated kansei engineering and text mining to delve into dynamic fresh food consumer needs, analyzing satisfaction factors through the implicit demand lens. These studies illustrate the feasibility of utilizing text mining based on online reviews to improve customer satisfaction and provide a set of analytical processes to build upon.

In summary, while existing research provides insights into service quality, subjective methods prevail, prompting the call for more objective approaches considering spatial and temporal dynamics. Leveraging text mining techniques from online reviews, this study aims to quantify service quality and satisfaction, while also exploring spatial and temporal influences, enriching the research landscape in fresh food e-commerce logistics.

2 Research methodology

2.1 Feature extraction for service quality of fresh e-commerce

In this paper, we apply LDA to user comments extracted from the JD Fresh platform, in conjunction with existing literature, to categorize and name dimensions representing evaluation indicators for fresh food e-commerce service quality. Subsequently, we construct a sentiment dictionary and calculate sentiment scores for each dimension, transforming textual data into numerical vector representations. For customer satisfaction measurement, we utilize additional crawled reviews labeled as "good" or "bad" from various e-commerce platforms as samples. Each review's expression is vectorized via Word2vec, and a SVM model is introduced for high-dimensional semantics classification training. The trained model predicts user satisfaction by embedding their JD Fresh platform reviews and, when combined with the distributed expression vector of evaluation indicators, allows exploration of different dimension impacts on user satisfaction.

2.2 Online review data collection and preprocessing

As a prominent fresh food e-commerce platform, JD Fresh's user evaluation data derive from actual product purchasers. These reviews encompass diverse aspects of the purchasing process, including product quality, logistics, and after-sales experiences. Public user information such as IP address and release time provides comprehensive data.

JD Mall stores are categorized into self-supporting and non-self-supporting entities. Self-supporting store shipment warehouses are relatively stable, facilitating logistics distance calculations. Consequently, we selected product reviews with the JD self-supporting logo for crawling.

Tab. 1: Classification of fresh food product selection

Category	Product
Fruits (17 kinds from 45 pages)	Cheerios, apples, oranges, coconut green, kiwi fruit, strawberries, pears, durian, blueberries, dragon fruit, cantaloupe, grapes, tangerines, grapefruit, lemons, passion fruit, watermelon
Vegetables (18 kinds from 28 pages)	Oilseed rape, broccoli, spinach, lettuce, pineapple, Chinese cabbage, oatmeal, corn, yams, sweet potatoes, pumpkin, chestnuts, ginger, onions, scallions, flat mushrooms, cucumbers, string beans
Meat, poultry and eggs (6 kinds from 40 pages)	Pork, duck, beef, chicken, lamb, egg
Aquatic products (10 kinds from 40 pages)	Yellow croaker, salmon, scallop, cod, white shrimp, Arctic sweet shrimp, crab, oyster, scallop, sea cucumber
Pasta and cooked food (10 kinds from 32 pages)	Hand Pie, noodle with meat sauce, siu mai, xiao long bao, soup dumpling, dumpling, mousse, pie, chicken tenderloin, meat dumpling

Source: Jingdong

Following fresh product categorization (fruits, vegetables, meat, poultry and eggs, aquatic products, pasta, and cooked food), we targeted top-selling categories on the JD platform for review crawling. This yielded 61 product types across 185 stores. Details of the fresh food category selection are presented in Tab. 1.

In this paper, we have collected two datasets, dataset 1 is the core data which is used for regression analysis and needs prediction, dataset 2 is used for training. In this light, we employ Python for crawling review data of selected products, and parse JSON response to extract customer IP addresses, creation times, ratings, review texts, and other relevant fields. Ultimately, we obtain 148,787 pieces of data from March 2023 to May 2024 (dataset 1), after filtering and removing 34,612 redundant comments lacking IP information or duplicates. Preprocessing, including word segmentation and stopwords removal, yields a dataset with words as the fundamental unit. Additionally, we collect 157,068 reviews of similar fresh food e-commerce types from January 2020 to May 2024 (dataset 2) to train the Word2vec-SVM model. We open source the code and data at https://github.com/allen-zqh/code-data-for-EM-journal.

2.3 Extraction of service quality evaluation indicators based on LDA

When composing reviews, consumers often focus on specific themes relevant to their shopping experiences. These themes or topics, comprising characteristic and emotion-laden words, are key aspects reflected in reviews. This study utilizes LDA to cluster review themes, subsequently assigning manual labels to these clusters, which serve as evaluation indicators for fresh food e-commerce service quality. The process involves:

i) Data preprocessing: removing meaningless and short words to construct an effective bag-of-words (BoW) model for LDA modeling.
ii) Determining the number of topics: evaluating perplexity and coherence. Observing the relationship between model indicators and topic numbers (Fig. 1), a significant inflection point is noted at nine topics, indicating optimal model performance, thus, nine topics are selected.
iii) LDA modeling: utilizing the word frequency-inverse document frequency (TF-IDF) to extract text features, followed by fitting the LDA model with 5 passes, batch model and filtering words whose frequency is less

Tab. 2: Summary of service quality – Part 1

Indicators	LDA	Keywords	Explanations
Quality assurance	#1	Fresh, packaging, data, taste, flavor	1. Received products that are fresh, of good quality and taste 2. Delivered with complete and clean packaging and undamaged products 3. There are cold storage measures, such as cold chain transportation, equipped with a warm box, and ice bags
	#2	Ice, pack, frozen, tender, rich	
Reliability	#3	Worthwhile, quality, recommendation, trust, brand	1. The firm is professional, reputable and trustworthy 2. Be able to deliver the goods on time, fast delivery speed 3. The delivered goods are consistent with the order information 4. Delivery personnel dress neatly and hygienically, formal and unified
	#4	Packaging, reassuring, logistics, punctual	
Responsiveness	#5	Morning, soon, next day, today	1. Timely response to orders and prompt delivery 2. In-transit logistics information is updated promptly and accurately 3. Timely after-sales processing, fast return, replacement and compensation 4. Timely customer service response, fast feedback on inquiries and complaints
	#6	Logistics, express, speed, order, fast	

Tab. 2: Summary of service quality – Part 2

Indicators	LDA	Keywords	Explanations
Empathy	#7	Courier, attitude, believe, express, thanks, praise, recommend, sachet, service	1. Provide personalized service to customers, can take the initiative to understand and meet customer needs 2. Delivery personnel service warm and courteous, good attitude 3. Be able to patiently answer customers' questions when communicating with them 4. Promptly inform customers of any precautions 5. Be able to take the initiative to remind and contact customers when delivering goods
Economy	#8	Price, event, affordable, bargain, supermarket, double 11, full discount, price performance ratio	1. Freight costs are cost-effective 2. The return logistics cost is reasonable and supported by shipping insurance 3. There are special offers for reduced shipping costs
Convenience	#9	Convenient, door-to-door, deliver to my home, just right, direct, no need, efficient, easy, quick	1. Wide range of logistics services, high coverage of distribution network 2. Flexible collection time, customers can choose the collection time independently 3. Flexible pickup mode, customers can independently choose to deliver to their doorsteps or pick up at the post station 4. Convenient operation of payment, return and exchange processes

Source: own

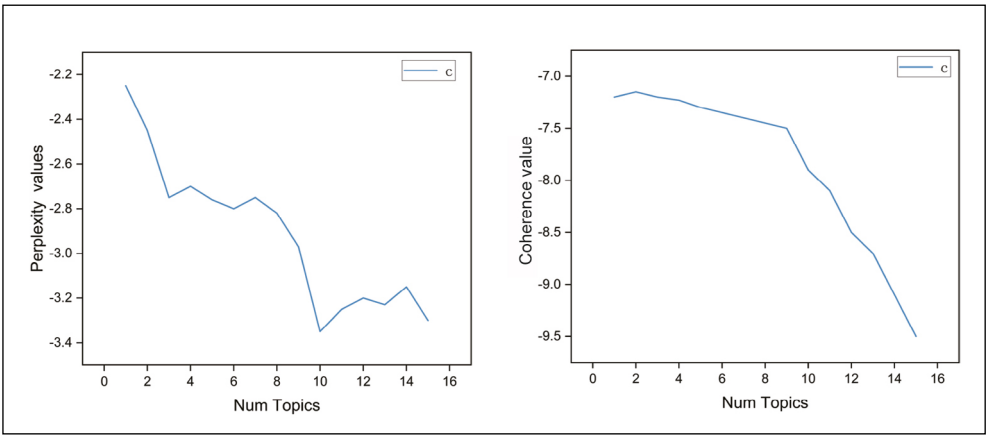

Fig. 1: Perplexity and coherence score and number of topics

Source: own

than 5. Upon model training completion, texts are assigned topics, and the probability distribution of each text belonging to each topic is computed as well.

Continuous adjustments to the stopword list and customized lexicon are made based on topic outputs from multiple experiments to minimize noise during clustering. Finally, six topics (indexes) are generalized by combining the classical scales such as SERVQUAL and LSQ, including quality assurance, reliability, responsiveness, empathy, economy, and convenience (Tab. 2).

2.4 Quantification of service quality in fresh food e-commerce

In constructing the emotional lexicon for analyzing online reviews, we delineate two predominant structures: "degree word + emotional feature word" and "degree word + negative word + emotional feature word." For instance, phrases like "not very fresh" exemplify these structures, with "very" serving as a degree word, "not" as a negative word, and "fresh" as an emotional feature word. Thus, the construction of the emotional lexicon entails the creation of dictionaries for emotional characteristics, negation words, and degree words.

i) Dictionary of emotional characteristics. We organize and optimize keywords obtained from LDA clustering and high-frequency words, aligning them with the six evaluation indicators of fresh food e-commerce service quality. This process yields a lexicon of logistic core words corresponding to each indicator.

ii) Dictionary of negation words. Drawing from existing Chinese negative word dictionaries available online, we identify and retain applicable negatives observed in fresh food e-commerce reviews. Irrelevant negatives are eliminated, resulting in the completion of the negation dictionary.

iii) Dictionary of degree words. Degree words modify or intensify the emotional intensity of an emotional word. We adapt an existing Chinese degree word dictionary, comprising 219 words categorized into six intensity levels. Additionally, we augment this dictionary with sentiment words extracted from high-frequency words in the sample data, relevant to fresh food e-commerce, such as "very good," "lightning speed," and "no complaints." These words are assigned values in the interval [0.5, 2], classified into six grades.

After constructing the sentiment lexicon, sentiment analysis is employed to quantify the sentiment value of each indicator's feature word in the reviews. The sentiment score of each sentiment feature word in a comment is calculated, and then the sentiment scores of the sentiment feature words belonging to each indicator are aggregated. This calculation is represented by Equation (1):

$$Sentiment = \sum_{i=1}^{n} \sum_{j=1}^{m} degree_j \times n_i \times negative^k \quad (1)$$

where: *sentiment* – the sentiment score of a topic in the comment; n_i – the emotional characteristics with $i = 1, 2, \ldots, n$; n – the number of emotional characteristics in the comment; $degree_j$ – the degree; $j = 1, 2, \ldots, m$, where m is the number of degree words neighboring the emotional characteristics; $negative^k$ – the negative word; k – number of negatives neighboring the emotional characteristics or degree word.

The constructed sentiment lexicon is employed to transform qualitative data into quantitative data, facilitating the calculation of scores for each review across the six indicators: quality assurance, reliability, responsiveness, empathy, economy, and convenience. A dataset comprising 125,027 valid entries was obtained.

2.5 Quantification of customer satisfaction

To enhance the accuracy of textual analysis, this study employs classification algorithms like logistic regression, random forest, and SVM for model training, assessing their performance using metrics such as precision, recall, and F1-score. Notably, the Word2vec-SVM model works better compared to conventional machine learning methods in previous studies (Yang et al., 2022). Hence, Word2vec is integrated with machine learning to encode evaluation sequences. By leveraging Word2vec-generated word vectors as input features for SVM classifiers, textual sentiment can be effectively classified and recognized. This approach combines the semantic information capture capability of Word2vec with the robust classification performance of SVM, enhancing the accuracy and efficiency of sentiment analysis.

Therefore, this paper utilizes Word2vec-SVM model to quantify customer satisfaction. Specifically, we used dataset 2 (157,068) for training.

Tab. 3: Satisfaction based on Word2vec-SVM

Origin comments	Consumer satisfaction	Overall statistics
The packaging was secure and well-sealed, and JD logistics delivered the package very quickly, arriving the next day. The cherries were large, tasted good, and were very fresh. Moreover, JD's pricing is quite reasonable, more competitive than supermarket prices. Highly recommended.	0.1000	Max: 1.0000 Min: 0.0000 Std: 0.3396 Mean: 0.8338
JD's self-operated delivery is incredibly fast. I placed the order last night, and it arrived early this morning. Some of the items were already dry, but they tasted great. I'll order again after finishing these. I've had my eye on this item for a while, and the promotion made it such a great deal. If you like it, don't hesitate!	0.9917	
I placed an order on November 25th, and it still hasn't shipped. This one, which I ordered a few days ago, shipped surprisingly fast. It came in a thermal box, and the quality is decent, though a few were spoiled. The taste is acceptable, slightly sour.	0.0784	
It feels like the items were ripened in cold storage; they don't taste particularly fresh.	0.0556	

Source: own

In order to avoid the tediousness of manual labeling, this paper collects reviews according to "good" (79,851) and "bad" (77,217), respectively. Secondly, after cutting words and removing stop words (like "is," "and," "to," "of"), Word2vec is used to vectorize the preprocessed text, where the word vector dimension is 500, the number of iterations is 10, and the low-frequency word threshold is 5. The model is trained using logistic regression, random forests, SVM, and Word2vec-SVM, respectively (Fig. 2). Finally, Word2vec-SVM with better results was selected to predict the 148,787 data (dataset 1) in this paper to obtain customer satisfaction scores (7:3 for selecting training and testing data, the kernel is "rbf," both verbose and probability are "true"). Tab. 3 shows some selected comments with predicted consumer satisfaction.

3 Empirical analysis

3.1 Variables

In this paper, the impact of the six evaluation indicators of fresh food e-commerce service quality on customer satisfaction is analyzed as a main effect in empirical analysis.

The explanatory variable is customer satisfaction, which is the probability of classification each text review as an input to the trained Word2vec + SVM model, in other words, the general level of satisfaction exhibited by each comment.

The core explanatory variables are the six indicators, which are quality assurance, reliability, responsiveness, empathy, economy, and convenience, and their specific interpretations are shown in Tab. 2, and the specific values are derived from the results of the sentiment value score. We trained and evaluated four different models for sentiment analysis: support vector machine (SVM), random forest, logistic regression, and a Word2Vec-based model. Each model has distinct characteristics. SVM is effective for high-dimensional text data classification and can handle non-linear decision boundaries. Random forest is robust to noise and helps prevent overfitting by averaging the results of multiple decision trees. Logistic regression is a linear model known for its simplicity and interpretability, often used for binary classification tasks like sentiment analysis. The Word2Vec-based model utilizes word embeddings to capture semantic relationships between words, making it particularly effective in understanding the context within text. We evaluated each model using precision, recall, and F1-score to select the best-performing one. Precision measures the accuracy of positive predictions, recall assesses the model's ability to identify all positive instances, and

F1-score provides a balanced metric of both precision and recall. The model with the highest F1-score was chosen as the final tool for sentiment analysis.

On the basis of the main effect, this study aims to delve deeper into how customer geographic location and purchase timing influence the primary effect's variation. Thus, customer location and purchase timing are transformed into interaction variables, which are then incorporated into the regression model for analysis. IP address information is

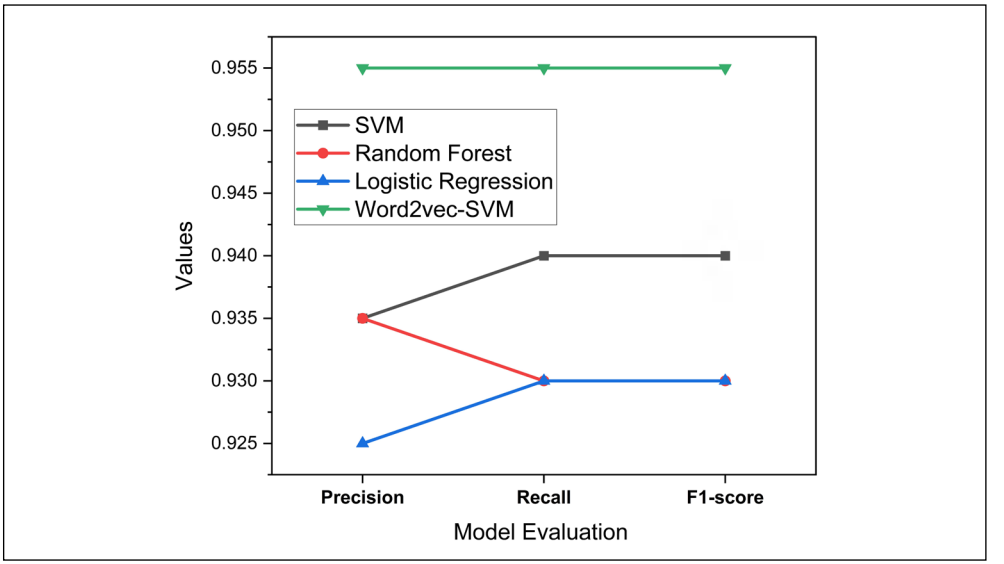

Fig. 2: Model evaluation summary

Note: The word vector dimension is 500; the number of iterations is 10; the threshold of low-frequency words is 5; dividing the training set and the test set in the ratio of 7:3.

Source: own

utilized to derive two specific variables: logistical distance and regional economic status. Additionally, purchase timing information is converted into a seasonal variable.

i) Logistics transportation distance. IP address for each review on the JD Fresh food platform is province-level. Consequently, the capital city in each province is considered the receiving location. Data collection encompasses 31 provinces in China, excluding Hong Kong, Macao, and Taiwan. The selected review data pertain to JD's own fresh goods, making cities housing JD's seven logistics centers the delivery locations.

Logistics distance herein refers to the spherical distance between the warehouses and receiving places. It operates under the assumption that JD opts for the warehouse closest to the receiving site for shipping. To facilitate computation, data is discretized using the natural breakpoint method, categorizing logistics transportation distances into seven categories. Larger values denote greater distances as shown in Fig. 3.

ii) Season. To elucidate the time variable, this study employs the four seasons, characterized by distinct temperature variations (seasons are delineated according to the northern hemisphere's Gregorian calendar, with spring spanning March, April, and May; summer covering June, July, and August; fall encompassing September, October, and November; and winter spanning December, January, and February). Typically, average temperatures follow the order: summer > spring = fall > winter. Thus, summer is assigned 3, spring and fall are assigned 2, and

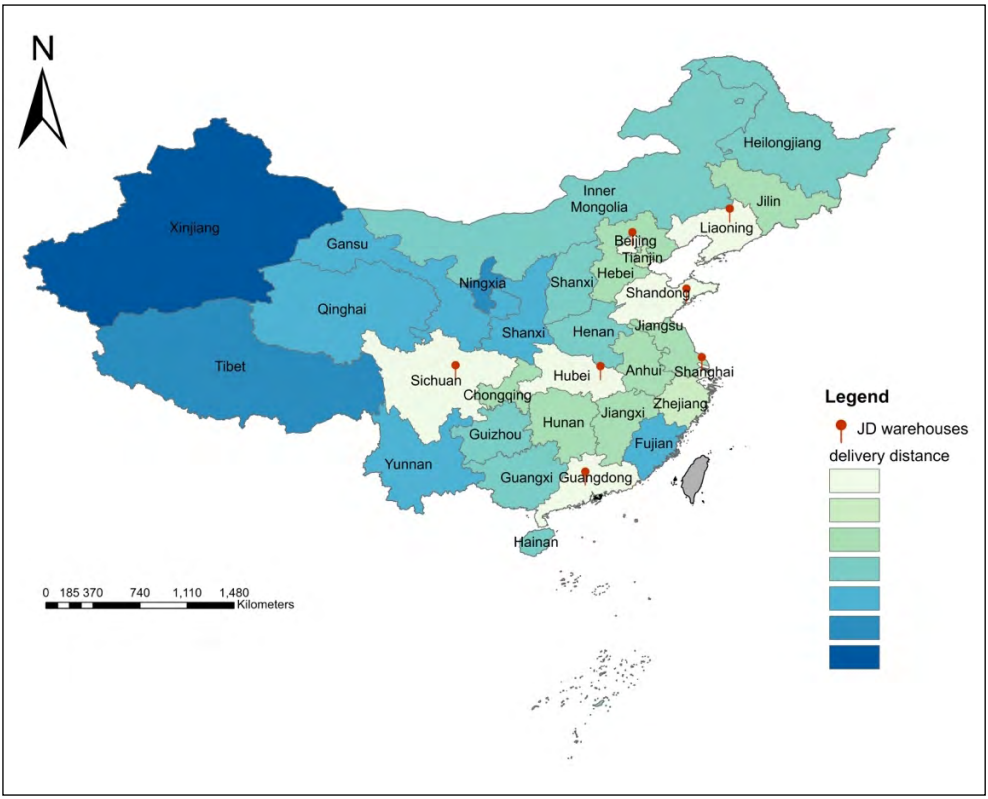

Fig. 3: Classification of logistics and transportation distances

Note: Hong Kong, Macao and Taiwan were not included due to lack of data.

Source: Jingdong and own

winter is assigned 1. Higher temperatures correspond to larger values in this scale.

iii) Regional economic level. This study employs GDP per capita data to depict the economic condition of consumers in each area, sourced from the China Statistical Yearbook 2023. Utilizing the natural breakpoint method, we categorized the economic status of each region into seven tiers. Larger values denote higher economic levels within the region. The descriptions of the variables are summarized in Tab. 4.

3.2 Regression model

In order to explore the influence of each indicator on customer satisfaction, we employ a multiple linear regression model for empirical analysis. The regression comprises main effect and interaction effect regression. The main effect examines the impact of each indicator of fresh e-commerce service quality on customer satisfaction. Conversely, the interaction effect scrutinizes how each indicator affects customer satisfaction under the perturbation of spatio-temporal factors, namely logistics transportation distance, economic level, and season.

1) Main effect model:

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{p=1}^{k} \sigma_p z_p + \varepsilon \quad (2)$$

2) Interaction effect model:

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \alpha_j m_j + \\ + \gamma_j m_j \sum_{i=1}^{n} x_i + \sum_{p=1}^{k} \sigma_p z_p + \varepsilon \quad (3)$$

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \alpha_j m_j + \\ + \gamma_j m_j \sum_{i=1}^{n} x_i + \sum_{p=1}^{k} \sigma_p z_p + \lambda + \varepsilon \quad (4)$$

Tab. 4: Summarization of variables and descriptions

Variable type		Symbol	Definition	Description
Control		C1	Price	Price per unit of fresh goods
		C2	Cumulative comments	Number of reviews for fresh products
		C3	Purchase frequency	Purchase times for each user
Independent	Core explanatory variables	X1	Quality assurance	Value obtained from the sentiment dictionary calculation
		X2	Reliability	
		X3	Responsiveness	
		X4	Empathy	
		X5	Economy	
		X6	Convenience	
	Interaction variables	M1	Logistics transportation distance	Distance from JD's own warehouse to the place of delivery
		M2	Regional economic level	GDP per capita in 2023 for all provinces and cities in the country
		M3	Season	3-classes according to temperature
Dependent		Y	Consumer satisfaction	Predicted value of Word2vec-SVM

Source: own

where: Y – customer satisfaction; β_0, β_1, β_2, .., σ_p – regression coefficients; $n = 6$; $k = 2$; x_i – the scores of each indicator of service quality of fresh e-commerce; $i = 1, 2, \ldots, 6$; m_j – the interaction variables, i.e., the values of logistics and transportation distances, economic levels, and seasons; $j = 1, 2, \ldots, 6$; z_p – control variables, i.e., the price of the product and the number of review entries; λ – the fixed effect of product type; ε denotes random error and $\varepsilon \sim N(1, \sigma^2)$.

3.3 Results

From the main effect regression results in Tab. 5, it is evident that enhancing quality assurance, reliability, responsiveness, empathy, economy, and convenience in logistics services is conducive to improving service quality. The degree of influence, ranked in descending order based on the size of coefficients, is as follows: quality assurance > economy > convenience > reliability > responsiveness > empathy. Quality assurance exerts the most substantial impact on service quality due to its direct correlation with product quality, especially considering the perishable nature of fresh products. The economy, holds the second-highest impact, indicating consumers' sensitivity to pricing, which significantly influences their shopping decisions and experiences. Convenience, reliability and responsiveness also have a positive impact on the evaluation of service quality, indicating that flexible pickup, safe and fast delivery of goods, the compatibility of goods and descriptions, the speed of shipment and the speed of customer service feedback, etc., are also the focus of customers. In contrast, the impact of empathy on service quality evaluation is relatively lower, suggesting that consumers may allocate less attention to factors like staff service attitude during the evaluation process.

The regression results for the interaction effects are shown in Tab. 6. We interpret them

Tab. 5: Main effect regression results

	Model 1	Model 2
Price	0.000***	0.000***
	(0.000)	(0.000)
Cumulative comments	−0.000***	−0.000***
	(0.000)	(0.000)
Quality assurance		0.068***
		(0.000)
Reliability		0.032***
		(0.001)
Responsiveness		0.030***
		(0.001)
Empathy		0.013***
		(0.001)
Economy		0.058***
		(0.001)
Convenience		0.072***
		(0.001)
_cons	0.773***	0.599***
	(0.002)	(0.002)
Type	Yes	Yes
Month	Yes	Yes
N	124,608	124,608
R^2	0.015	0.310

Note: Robust standard errors calculated in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: own

in the following three aspects: interaction effect with logistics transportation distance; interaction effect with regional economic level; interaction effect with season.

Interaction effect with logistics transportation distance

Firstly, the interaction effect between logistics transportation distance and quality assurance is found to be negative and significant. This suggests that as the distance increases, consumers may expect a wider range of acceptable quality due to longer transportation times.

Similarly, the interaction effect between logistics transportation distance and economy also shows a negative significance, indicating that longer transportation distances diminish the influence of economy on customer satisfaction. Higher postage charges for distant regions, as practiced by JD self-supporting, may contribute to this trend. For example, in many free shipping products, it is stated that Xinjiang, Tibet and other remote areas are excluded. This practice makes consumers from remote areas accustomed to the cost of postage, resulting in a reduction of their economic sensitivity.

Moreover, the interaction effect between logistics transportation distance and responsiveness is negatively significant, that longer transportation distances tend to reduce

the impact of responsiveness on customer satisfaction. The inherently longer transportation time in remote areas diminishes the marginal benefit of delivery speed, reducing consumer attention to responsiveness. In addition, by going back to the product details page, we found that when the transportation distance is farther away from the region, JD generally do not provide perishable fresh food delivery service. Therefore, consumers in these areas are more able to purchase fresh products that are relatively less susceptible to damage and spoilage, such as instant food products with packaging and relatively long shelf life, as well as fruits and vegetables with hard skin, which also reduces consumer demand for timely delivery.

Interestingly, the interaction effect between logistics transportation distance and

Tab. 6: Regression results of interaction effects – Part 1

	Model 3	Model 4	Model 5
Price **Cumulative comments**	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)
Quality assurance **Reliability**	−0.000***	−0.000***	−0.000***
	(0.000)	(0.000)	(0.000)
Responsiveness **Empathy**	0.068***	0.068***	0.046***
	(0.000)	(0.000)	(0.001)
Economy **Convenience**	0.032***	0.032***	0.022***
	(0.001)	(0.001)	(0.002)
Logistics transportation distance **Quality assurance – distance**	0.030***	0.030***	0.024***
	(0.001)	(0.001)	(0.002)
Reliability – distance **Responsiveness – distance**	0.013***	0.013***	0.007***
	(0.001)	(0.001)	(0.002)
Empathy – distance **Economy – distance**	0.058***	0.058***	0.044***
	(0.001)	(0.001)	(0.002)
Convenience – distance **Regional economic level**	0.072***	0.072***	0.072***
	(0.001)	(0.001)	(0.001)
Quality assurance – economy **Reliability – economy**	−0.000***		
	(0.000)		
Responsiveness – economy **Empathy – economy**	−0.000***		
	(0.000)		
Economy – economy **Convenience – economy**	0.000		
	(0.000)		
Season **Quality assurance – season**	−0.000**		
	(0.000)		
Reliability – season **Responsiveness – season**	0.000		
	(0.000)		
Empathy – season **Economy – season**	−0.000*		
	(0.000)		

Tab. 6: Regression results of interaction effects – Part 2

	Model 3	Model 4	Model 5
Convenience – season	0.000*		
Price	(0.000)		
Cumulative comments		0.000***	
Quality assurance		(0.000)	
Reliability		−0.000	
Responsiveness		(0.000)	
Empathy		−0.000	
Economy		(0.000)	
Convenience		0.000	
Logistics transportation distance		(0.000)	
Quality assurance – distance		0.000	
Reliability – distance		(0.000)	
Responsiveness – distance		−0.000**	
Empathy – distance		(0.000)	
Economy – distance		−0.000***	−0.000***
Convenience – distance		(0.000)	(0.000)
Regional economic level			−0.034***
Quality assurance – economy			(0.001)
Reliability – economy			0.013***
Responsiveness – economy			(0.001)
Empathy – economy			0.006***
Economy – economy			(0.001)
Convenience – economy			0.003***
Season			(0.001)
Quality assurance – season			0.004***
Reliability – season			(0.001)
Responsiveness – season			0.008***
			(0.001)
_cons	0.600***	0.599***	0.711***
	(0.002)	(0.002)	(0.004)
Type	Yes	Yes	Yes
Month	Yes	Yes	Yes
N	124,608	124,608	124,608
R^2	0.310	0.311	0.319

Note: Robust standard errors calculated in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: own

convenience is significantly positive, indicating that longer transportation distances increase the impact of convenience on customer satisfaction. Underdeveloped logistics infrastructure in remote areas may lead to difficulties in the "last kilometer" transportation and service guarantee, prompting consumers to prioritize flexible and convenient pickup options.

However, the regression coefficients of the interaction terms between transportation distance and reliability and empathy are not significant, indicating that transportation distance does not significantly influence consumer attention to these attributes.

Interaction effect with regional economic level

The regression analysis reveals intriguing insights regarding the relationship between the economic level of a region and various aspects of customer satisfaction in fresh food e-commerce. Specifically, the negative regression coefficient between economic level and economy suggests that in economically developed regions, affordability has a greater impact on customer satisfaction. This phenomenon stems from the higher purchasing power and reduced-price sensitivity of consumers in such areas compared to those in less developed regions.

However, the negative regression coefficients of both interaction terms of economic level with quality assurance and convenience are noteworthy. They imply that in economically developed regions, the influence of quality assurance and convenience on customer satisfaction diminishes. This trend may be attributed to the higher logistics standards and more comprehensive infrastructure in economically advanced areas, resulting in shorter transportation times and higher product freshness. Moreover, consumers in these regions may be accustomed to receiving quality goods and utilizing convenient pickup methods, thus these factors have less impact on their overall evaluation of fresh food e-commerce services.

Conversely, the positive regression coefficient of the interaction term between regional economic level and empathy indicates that in more economically developed regions, the impact of empathy on customer satisfaction is heightened. Consumers in these areas often have higher expectations regarding the service attitude and quality of delivery and customer service personnel. Based on a selection of representative comments (e.g., *Now frozen deliveries are either called or delivered to your door, but they just put it on the doorstep and walk away – Shanghai; The delivery guy comes to the door at 1:00 p.m., the kids are asleep, and he's rude enough to keep ringing the doorbell, can't he be a little quieter? – Beijing*), it is evident that consumers in economically developed regions have specific expectations regarding logistics service empathy.

However, the negative regression coefficient of the interaction term between regional economic level and reliability suggests that the influence of reliability on customer satisfaction may decrease in economically developed regions. This could be attributed to the prevalence of reliable logistics and distribution systems, resulting in the safe and timely arrival of goods becoming commonplace, thus receiving less attention in consumer reviews.

Interaction effect with season

The regression analysis in Tab. 5 reveals significant positive coefficients for the interaction terms between season and various service quality dimensions, including quality assurance, reliability, economy, empathy, and convenience.

Specifically, the positive regression coefficients of the interaction terms of season with quality assurance, as well as reliability, suggest that the hotter the season, the greater the effect of these attributes on customer satisfaction. This is due to the fact that in summer, when the weather is hot, fresh food is prone to corruption and deterioration, and the work of preservation is more difficult, and there will be higher requirements for the management of cold chain logistics, temperature control during transportation and storage, and speed of delivery, so that problems occurring in the logistic process are also more likely to be detected by consumers, and the consumers' evaluations of the warranty and reliability are more prone to fluctuate accordingly.

Unexpectedly, the regression coefficients of the interaction term between season and empathy and convenience are also significantly positive, indicating that the hotter the season, the greater the impact on customer satisfaction. As tracing the original comments reveals that when the weather is hot, consumers will have more obvious empathy for the delivery personnel, be more sympathetic to their labor, and be

more appreciative of home delivery and other actions that can increase convenience, and will mention it more in their comments to express their gratitude, thus increasing the impact of convenience and empathy on satisfaction (e.g., *Mushroom package has been received, thanks to the Jingdong delivery, the box is intact, there is an ice pack. The courier has a good attitude of service, though summer is hot, you have worked hard*).

Similarly, economy, which should be independent of the season, shows a positive and significant relationship here, suggesting that the effect of economy on customer satisfaction increases in hotter seasons. By tracing the comments in the summer, we found that a large number of comments mentioned the words "event," "discount" and "subsidies," suggesting that this result may be related to JD's "618" campaign. Although there is multiple "shopping festivals" in a year, because "618" originates from JD, JD's preferential and promotional efforts will be greater than other shopping festivals, and consumers are more likely to associate "618" with JD. As a result, the organization of large-scale promotional activities will attract more economically sensitive consumers, leading to a significant increase in consumers' attention to economy.

Although the coefficient for the interaction term of season with responsiveness is only positively significant at the 10% level, it still suggests that the season will increase the effect of responsiveness on customer satisfaction to some extent. The reason for this may be due to the temperature will have a certain impact on human emotions, research has shown that summer is prone to "emotional heat stroke" phenomenon, people are relatively easy to produce impatient emotions, which may also lead to the increase in the responsiveness of the logistics service requirements.

3.4 Heterogeneity analysis based on consumer type of first-time and repeated

In addition to the core logistics service quality and spatiotemporal factors influencing customer satisfaction, consumers' purchasing experiences also shape their expectations and perceptions of service. For instance, first-time buyers may have different expectations compared to repeat purchasers. To validate the robustness of our findings across other platforms and account for purchase frequency, we collected 278,705 JD Jingzao reviews – JD Jingzao being JD's curated shopping platform, which operates differently from JD's main platform. Unlike dataset 1, which includes both self-operated and third-party businesses, JD Jingzao is fully self-operated under a distinct brand. This dataset includes consumer purchase frequency data, centralizing it alongside the five logistics service quality factors for further regression analysis. The results are presented in Tab. 7.

Tab. 7: Heterogeneity analysis – Part 1

	Model 6	Model 7
Price	0.011***	0.011***
	(0.001)	(0.001)
Comments	−0.020***	−0.020***
	(0.001)	(0.001)
Quality assurance	0.044***	0.044***
	(0.001)	(0.001)
Reliability	0.052***	0.052***
	(0.001)	(0.001)
Responsiveness	0.038***	0.038***
	(0.001)	(0.001)

Tab. 7: Heterogeneity analysis – Part 2

	Model 6	Model 7
Empathy	0.015***	0.015***
	(0.001)	(0.001)
Economy	0.056***	0.056***
	(0.001)	(0.001)
Convenience	0.042***	0.043***
	(0.001)	(0.001)
Quality assurance – purchase		−0.000
		(0.000)
Reliability – purchase		−0.000
		(0.001)
Responsiveness – purchase		−0.002***
		(0.001)
Empathy – purchase		−0.002***
		(0.001)
Convenience – purchase		−0.005***
		(0.001)
_cons	0.709***	0.709***
	(0.001)	(0.001)
Type	Yes	Yes
N	278,705	278,705
R^2	0.222	0.222

Note: Robust standard errors calculated in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: own

As shown in Tab. 7, the impact of the five logistics service quality factors on satisfaction remains consistent with previous findings, affirming the robustness of our results. Additionally, the key interaction terms – responsiveness, empathy, and convenience – are significantly negative at the 1% level. This suggests that the marginal utility of logistics service quality decreases as consumers' purchase experience increases, highlighting that repeat customers tend to have more stable and demanding service expectations compared to new customers. Furthermore, drawing on the two-factor theory in e-commerce and customer satisfaction (Alshmemri et al., 2017), these significantly negative factors align more with "attraction" attributes, as opposed to basic factors like assurance and reliability, particularly in the context of fresh goods. These attributes play a greater role in enhancing customer satisfaction and overcoming perception bottlenecks (Yang & Huang, 2024). This finding also indicates that experienced consumers prioritize further improvements in service quality.

Conclusions and discussion

This paper investigates the impact of fresh food e-commerce service quality on customer satisfaction using online reviews from JD Fresh. Firstly, based on LDA model, topic clustering was carried out on online reviews, six evaluation indicators of fresh food e-commerce service

quality were identified, and each indicator was scored by using sentiment analysis; secondly, the customer satisfaction of the reviews was measured by machine learning. Based on the measurement results, we explored the impact of fresh e-commerce service quality on customer satisfaction; innovatively, we introduced spatial and temporal factors, including logistics transportation distance, regional economic level, and season, as interaction variables. Through regression analysis, we examined the influence of service quality indicators on customer satisfaction, along with the perturbation effects of temporal and spatial factors.

Our findings highlight that: i) Based on users' online reviews, the evaluation indicators of fresh food e-commerce service quality can be summarized as quality assurance, reliability, responsiveness, empathy, economy, and convenience. ii) From the results of the main effects, quality assurance, reliability, responsiveness, empathy, economy, and convenience all have a positive and significant impact on customer satisfaction, and quality assurance > economy > convenience > reliability > responsiveness > empathy, indicating that quality assurance has the greatest impact on customer satisfaction and is most valued by consumers, which is similar to previous results of service quality in Parasuraman et al.'s (1998) research. But the result of importance is opposite to Yang et al.'s (2024) study for emotional service can better improve consumer satisfaction, which suggests that there are boundaries that influence consumer satisfaction, such as temporal-spatial factors and consumer purchases mentioned later. iii) From the results of interaction effect, the further the logistics transportation distance is, the impact of quality assurance, economy and responsiveness on customer satisfaction will be weakened, and the impact of convenience on customer satisfaction will be strengthened, which is the same effect of distance on consumer textual emotion (Neumann et al., 2023). The higher the economic level is, the impact of economy, quality assurance, convenience and reliability on customer satisfaction will be reduced, and empathy has an increased effect on customer satisfaction, which is also aligns with the impact of economic value perception on consumer decisions (Istanti et al., 2020). The higher the temperature season, the effect of all six attributes on customer satisfaction is significantly increased. iv) For the heterogeneity analysis of consumer purchase times, compared with first-time users, repeated customers with more purchases have higher requirements for logistics services, especially focused on charm factors, it corresponds to the asymmetric relationship between consumers with different visit frequencies (Schofield et al., 2020).

Our empirical results shed light on improving the logistics services of fresh food e-commerce. For example, firms should prioritize the improvement of quality assurance over the improvement of service quality. The results of the interaction effects provide some more specific strategic directions: from the perspective of transportation distance, fresh food e-commerce companies should enhance local customer service support in areas with shorter transportation distance to respond to consumer demand faster; while for remote areas, they need to improve the construction of logistics support facilities. From the perspective of the level of regional development, firms need to strengthen the level of personalized service to consumers in economically developed regions; more targeted preferential events for consumers in less economically developed regions. From the seasonal point of view, firms need to strengthen the control of quality assurance in the hot season; and appropriately increase the number of employees and employee care, in order to help incentivize the delivery staff to improve the level of service, so as to enhance the overall evaluation of the quality of service to consumers. Moreover, firms can differentiate their services according to the type of consumers (first-time or repeated). They can use attract strategy for first-time consumers and retaining method for repeated consumers (Yang et al., 2024). Finally, large platforms like JD and Alibaba should leverage AI and big data technologies to optimize regional logistics and enhance cold chain capabilities, ensuring freshness and quality across all regions. Meanwhile, small to medium-sized companies, which often rely on third-party logistics, should focus on building flexible delivery networks and maintaining strong communication with customers to enhance satisfaction.

Additionally, this model can be adapted for use on other e-commerce platforms such as Alibaba and Amazon, which may have different logistics frameworks and customer expectations. For instance, in third-party logistics models commonly used by Amazon, reliability and responsiveness might play a more crucial role compared to JD's self-operated logistics.

Similarly, in international markets, cultural and regional differences could influence which aspects of logistics are most valued by customers. Adapting this model to different regions could involve reweighting specific logistics attributes to better reflect local preferences. Moreover, the model could be extended to different markets and logistics models. In regions where cold chain logistics are less developed, factors like reliability and timeliness may dominate customer satisfaction, while in developed markets, the focus may shift to convenience and responsiveness. Exploring how this model performs in these diverse environments can provide a more comprehensive understanding of the logistics satisfaction dynamics in fresh food e-commerce.

This study has limitations that we wish the future study to address. First of all, although we provided data for the hybrid operating model, the logistics scene for fresh food e-commerce is relatively narrow. Because different fresh food e-commerce companies in different countries have unavoidable differences, such as Taobao, Jingdong, Tiktok. Besides, since the secondary data from e-commerce platforms, we are unable to capture socio-demographic characteristics of consumers such as age and gender. Future research can consider a more detailed categorization of the logistics model of fresh food e-commerce and comparative analysis to make the results more precise in other regions outside of China. Follow-up studies can also incorporate questionnaires to compensate for demographic attributes as the mixed method. Finally, the accuracy of text analysis needs to be improved. Future research could build on this work by applying more advanced sentiment analysis techniques, such as deep learning models and aspect-based sentiment analysis (ABSA). Deep learning models, such as BERT and Transformer, can capture nuanced emotional expressions and improve sentiment classification accuracy. Meanwhile, ABSA would allow a more detailed examination of specific logistics service dimensions (e.g., delivery speed, product quality), offering a more granular understanding of their influence on customer satisfaction (Hajek et al., 2023; Huang et al., 2023).

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Emerging trends in food consumer behavior in Romania: A PLS-SEM approach

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Abstract: *The agri-food market is in constant flux, influenced by economic, social, and technological factors, as well as recent challenges such as economic and health crises. In this context, consumer behavior adjusts dynamically under the influence of needs, desires, and environmental factors, aligning with market demands and conditions. The proposed research focuses on emerging trends in food consumer behavior in Romania, emphasizing the determinants of economic decision-making. To this end, data was collected through a questionnaire and processed using partial least squares structural equation modelling (PLS-SEM), revealing the role of key factors shaping consumer behavior. The study identified two major categories of influential factors in food consumption within the Romanian market: determining factors (age, gender, income, and education) and sensitive factors (consumer psychology and market characteristics). These factors contribute to the development of behaviors aimed at saving, responsible consumption, and a healthy lifestyle. Based on the research findings, the study proposes measures to support responsible consumption and facilitate decision-making processes, considering the shared interests of consumers and retailers in adapting to current market trends.*

Keywords: *Food preferences, motivational factors, planned behavior, unplanned behavior, responsible consumption, Romania.*

JEL Classification: *E21, E27, R20, R22, Q18.*

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Introduction

The global macroeconomic and geopolitical context that has recently impacted the Romanian economy has also left its mark on the development of the food market and, implicitly, the entire food supply chain. Under these circumstances, markets are constantly undergoing change and adaptation, driven by socio-economic development, increasing consumer demands, technological innovations,

diversification of commercial activities, the rise of digitalization, as well as economic and health crises (Chivu et al., 2020).

As a result, consumers today shape their behavior under the influence of desires, needs, and factors that their purchasing and food consumption decisions. The buying and consumption behavior of individuals evolves under the cumulative impact of these factors to better meet demands and adapt to market conditions in general.

Starting from these considerations, the aim of this paper is to highlight the existence of certain purchasing and consumption habits that influence choices and alter consumer behavior, as well as the potential emergence of specific consumption patterns that shape the development of the entire food supply chain and offer new business models. In this context, consumer behavior undergoes multiple transformations, evolving from a simple model focused on meeting specific needs and rationality to a complex behavior influenced by emotions, experiences, lifestyle, and values.

The study seeks to establish a correlation between programmed and unprogrammed consumer behavior by analyzing the relationship between needs and rationality versus emotions and experiences. The importance of the study lies in presenting the main consumption patterns observed in the post-pandemic era, patterns that reveal adaptation and change across the entire food supply chain. These patterns emerge in a period of unpredictable and rapid changes, where societal and global values are constantly shifting, presenting challenges for each consumer's social existence.

The research highlights the existence of certain purchasing and consumption patterns that have become established in recent times. These patterns can be categorized as either programmed and conditioned behaviors that respond to specific consumer needs or unprogrammed and unconditioned behaviors influenced by sensations and emotions. It proposes aligning with a particular economic or psychological consumption model, and these patterns reveal how consumers are influenced by their social environment, time, past experiences, or the adoption of a particular lifestyle.

The research is logically and coherently structured, presenting the theoretical framework of the paper based on the analysis of the specialized literature and grounded in the objectives and hypotheses formulated in the introductory section.

Subsequently, the review of the literature and the research methodology are presented, forming the basis for the results, discussions, and conclusions, which synthesize the significance of the analyses conducted. Additionally, the paper highlights the limitations of the research and the potential avenues for its further expansion.

1 Theoretical background

Romanian consumers have recently shown an increasing interest in healthy and high-quality food. Pop (2022) analyzed consumer behavior in the nut market, highlighting the preference for products perceived as beneficial to health, especially among the urban population. Similarly, related studies indicate that health concerns are correlated with growing interest in organically certified products (Stanciu, 2022).

Nutritional imbalances remain a significant issue among the younger generation in Romania. Popescu et al. (2015) emphasized the tendency of young people to adopt unhealthy eating habits, influenced by a hectic lifestyle and the accessibility of fast-food products. The authors suggest that educational interventions are essential for changing this behavior.

In her doctoral research on consumer behavior regarding Romanian vegetables, Sanda (2016) examined the phenomenon of ethnocentrism and its influence on vegetable purchasing behavior in Romania. A high level of ethnocentrism within a population favors domestic products over imports, and understanding this level can help establish effective strategies to promote Romanian vegetables. After 26 years of transition to a market economy, the domestic population has reached an intermediate stage, where nationalist motives increasingly dominate the food purchase process.

The COVID-19 pandemic brought significant changes to food behavior. According to a study by Stanciu et al. (2020), Romanians became more mindful of food expenses, opting for well-known brands and products considered healthy. The pandemic also accelerated the digitization of the food purchasing process, a phenomenon observed in other regional countries. During lockdowns, Romanians rediscovered an interest in organic or at least natural foods, avoiding food waste, and showing greater environmental concern.

A study on Romanian consumer behavior during the pandemic by Mureșan et al. (2022) found that women were more concerned with socio-economic aspects and food waste compared to men. At the same time, older individuals were more focused on eco-friendly, socio-economic, and health-related food characteristics compared to younger groups. Entrepreneurs interested in developing social enterprises that provide food-related goods and services to vulnerable populations must also consider food consumer behavior, especially among disadvantaged groups or those with special needs.

A study by MKOR Consulting (2022) shows that interest in sustainable and ethical products is growing, especially among younger consumers. Consumers are increasingly concerned about the environmental impact of food products, with brands adopting sustainable practices gaining popularity.

A report by ANSVSA and INSP (2019) highlighted Romanian dietary preferences and consumption habits, providing a detailed perspective on meat, dairy, and vegetable consumption. The study also emphasizes how rising incomes influence dietary diversification. An interesting trend regarding consumer perceptions of organic versus traditional products was noted by Feldmann and Ham (2015). Compared to organic foods, local foods are not perceived as expensive. However, consumers are willing to pay a premium for local foods. The authors' predominantly quantitative research assessed consumer characteristics, attitudes, and purchasing behaviors regarding local foods.

Steenkamp (1997) remarked that food occupies an essential place in consumers' lives, serving as a source of nutrients and hedonic experiences. Food fulfils social and cultural functions and represents a significant part of consumer expenditure. However, consumer behavior related to food has not attracted systematic research due to the complexity and diversity of influences involved in food choice and consumption. Such research also requires knowledge and perspectives from a wide range of scientific and social science disciplines, including food science, nutrition, medicine, psychology, physiology, psychophysics, sociology, economics, marketing, and anthropology.

The added value and perceived quality of food along the agri-food value chain depend on both market demand and consumer preferences. In highly digitalized societies, social networks can play an important role in redefining the quality and value of food products. From this perspective, the impact of social media platforms, especially Facebook, can be significant for the sustainability of food consumption (Constantin et al., 2021).

Makowska et al. (2024) conducted a study on Polish consumers across Baby Boomers, X, Y, and Z generations. Key factors in food selection among Polish consumers include product quality, price, and nutritional information. Older generations (Baby Boomers and Generation X) prioritized food quality, while younger generations (Generation Y and Z) emphasized price. The research revealed statistically significant differences between generations regarding the product's country of origin, with older generations placing greater importance on this aspect. The oldest group (Baby Boomers) considered ecological certification the most important. Over 85% of Poles check product expiration dates while shopping, and 82.8% buy only the quantities they need. Baby Boomers are considered the most responsible of all generations.

Research objectives:

RO1: Analysis of food consumption in relation to situational influences that determine consumer decisions and choices.

RO2: Highlighting specific consumption patterns observed in the current stage of the food market.

RO3: Presenting practical solutions for the development of the food system and the modelling of commercial businesses.

Working hypotheses:

H1: The impact of demographic factors on planned behavior.

H2: The impact of demographic factors on unplanned behavior.

H3: The impact of demographic factors on responsible consumption.

H4: The impact of demographic factors on food safety.

H5: The impact of experiential consumption and information sources on consumption.

2 Research methodology

2.1 Research design

The aim of this research was to highlight the presence of specific consumption patterns

within the food market, patterns developed because of the impact of demographic, economic, social, and psychological factors. To achieve this aim, a survey was designed based on a review of the specialized literature, using a questionnaire with 35 questions as the primary research instrument.

The structure of the questionnaire and variable selection followed general recommendations for multivariate research designs (Tabachnick & Fidell, 2013). The questionnaire was administered between March and June 2024 and distributed online via Google Forms, institutional email, or Microsoft Teams to groups of students, pupils, and other trainees participating in various institutional training programs. A total of 417 responses were validated.

The questionnaire was structured with items measured on a 5-point Likert scale and included multiple scales specific to the variables of this research. The collected data were processed using partial least squares structural equation modelling (PLS-SEM), a method considered suitable due to its ability to simultaneously analyze multiple independent and dependent variables, test mediation relationships, handle relatively small sample sizes, and address multicollinearity issues. This approach aligns with the methodological principles for multivariate analysis outlined by Tabachnick and Fidell (2013).

Consumer behavior was analyzed through the lens of the motives driving specific consumption behaviors (whether conditioned or unconditioned) as well as the factors influencing choices at a given moment, including personal, psychological, situational factors, or those related to the marketing mix. Analyzing consumer behavior and identifying trends in the purchasing process allows for the identification of specific consumption patterns based on these factors.

2.2 Definitions and measurements

Programmed behavior (PB). Programmed behavior is the behavior that is always related to a specific situation or context. Certain situational influences arise from factors independent of the consumer or the necessity of purchasing specific goods. Programmed behavior is motivated and conscious behavior that addresses consumer needs. This type of behavior reflects a specific way of acting, shaped by prior learning, and represents a behavioral pattern formed over time. The questionnaire items analyzed highlight the existence of intentionality focused on aspects such as avoiding consumerism tendencies and filtering impulses for excessive consumption.

The statements used to describe these aspects of rationality in consumer choices cantered on creating a shopping list (PB1), purchasing high-quality goods (PB2), meal planning (PB3), cooking meals based on needs (PB4), avoiding food waste (PB5), reasons strictly related to the necessity of purchases (PB6), and price (PB7). The research employed a Likert scale, with evaluations ranging from “to a very small extent (1)” to “to a very large extent (5).”

Unprogrammed behavior (UB). Unprogrammed behavior is when some consumers are socially oriented, focusing on others’ opinions and recommendations, while others are driven primarily by their emotions and impulses. Generally, unprogrammed behavior is unconditioned and involuntary, influenced by emotional factors, moods, and personal needs that are explainable. The explanation and analysis of unprogrammed consumer behavior were based on items describing impulsive purchases or previous experiences. Response statements included factors such as brand (UB4), warranty (UB5), product availability (UB6), intrinsic characteristics (UB7), design (UB8), packaging (UB9), shelf arrangement (UB1), the importance of a purchase (UB2), and perceived utility (UB3).

Responsible consumption (RC). Responsible consumption corresponds to a sociocultural model influenced by social norms and involves adopting a healthy and sustainable lifestyle driven by social pressures. Considering that responsible consumption reflects altruistic behavior, emphasizing awareness of the impact of dietary habits and strictly necessary purchases, the analysis included questionnaire items representing consumer orientation towards saving rather than consuming.

The responses highlighted the importance consumers place on the following aspects: avoiding food waste (RC8, corresponding to PB5), purchasing quality goods (RC5, corresponding to PB2), meal planning (RC6, corresponding to PB3), cooking within necessity limits (RC7, corresponding to PB4), creating a shopping list (RC4, corresponding to PB1), prioritizing consumption decisions (RC1), available income (RC2), and price levels (RC3).

The connection between responsible consumption and programmed behavior is defined by addressing specific needs at a given moment.

Food safety (FS). Food safety is an essential criterion in the choice of food products, alongside price and taste. Given the omnipresent concerns of Romanians regarding safe purchases for health and nutrition, the questionnaire included items addressing these aspects. The elements analyzed included brand (FS9, corresponding to UB4), warranty (FS8, corresponding to UB5), product availability (FS7, corresponding to UB6), product characteristics (FS6, corresponding to UB7), ingredients (FS3), design (FS5, corresponding to UB8), packaging (FS4, corresponding to UB9), product traceability (origin and provenance – FS1, sustainability certifications – FS2), as well as labelling and ingredients (FS10). The connection between food safety and unprogrammed behavior is explained by previous shopping experiences.

3 Results and discussion

The characteristics of the respondents are presented in Tab. 1. Most respondents are female, representing a significant proportion of 58.5%. Additionally, most respondents are aged between 31 and 55 years, representing the adult group, which accounts for 42% of the sample.

Tab. 1: Characteristics of respondents

Categories	Description	Frequency	
		Total	Percent (%)
Sex	Male	173	41.5
	Female	244	58.5
Age	Youth (18–31 years)	166	39.8
	Adults (31–55 years)	175	42.0
	Elderly (over 55 years)	76	18.2
Studies	High school education	217	52.0
	Bachelor's degree	129	30.9
	Master's degree	62	14.9
	Doctorate	9	2.2
Income (EUR)	Below 400	80	19.2
	400–800	201	48.2
	800–1,200	100	24.0
	Over 1,200	36	8.6

Source: own

Regarding education, the largest share of respondents has completed high school, making up 52% of the total. In terms of income level, the largest segment of respondents, representing 48.2%, corresponds to those earning between EUR 400 and EUR 800.

3.1 Descriptive statistics

The results of the descriptive statistics are presented in Tab. 2 and include the values for the mean, standard deviation, median, and mode.

3.2 Structural model analysis

The relationship between the measurement indicators and the construct was evaluated through the measurement model analysis, which included the assessment of their reliability and validity (Tab. 3).

Additionally, the analysis examined the reliability of the items and constructs, as well as the convergent and discriminant validity of the constructs. To assess the reliability and convergent validity of the construct, Cronbach's alpha coefficient, composite reliability (CR),

Tab. 2: Descriptive statistics

Constructor		Mean	Category	
Programmed behavior		3.5	To a small extent	
Unprogrammed behavior		3.2	To a moderate extent	
Responsible consumption		3.5	To a small extent	
Food safety		3.2	To a moderate extent	
Item	**Mean**	**Median**	**Mode**	**SD**
PB1	3.4	3.0	5	1.4
PB2	3.4	4.0	4	1.1
PB3	3.3	3.0	4	1.2
PB4	3.5	4.0	4	1.2
PB5	3.6	4.0	4	1.2
PB6	3.6	4.0	5	1.3
PB7	3.7	4.0	4	1.1
UB1	3.2	3.0	3	1.1
UB2	3.0	3.0	3	1.1
UB3	3.1	3.0	3	1.1
UB4	3.2	3.0	3	1.1
UB5	3.1	3.0	3	1.1
UB6	3.1	3.0	4	1.1
UB7	2.8	3.0	4	1.2
UB8	3.5	4.0	4	1.1
UB9	3.5	4.0	4	1.0
RC1	3.6	4.0	5	1.3
RC2	3.7	4.0	4	1.1
RC3	3.8	4.0	4	1.1
FS1	3.0	3.0	3	1.3
FS2	3.0	3.0	3	1.1
FS3	3.7	4.0	4	1.1
FS4	3.5	4.0	3	1.1

Note: The response mean criterion: (1) 1.00 < a < 1.79: to a very small extent, (2) 1.80 < a < 2.59: to a small extent, (3) 2.60 < a < 3.39: to a moderate extent, (4) 3.40 < a < 4.19: to a large extent, (5) 4.20 < a < 5.00: to a very large extent. PB – programmed behavior; UB – unprogrammed behavior; RC – responsible consumption; FS – food safety.

Source: own

and average variance extracted (AVE) were calculated. All results obtained for the analysed factors indicate excellent internal consistency, with Cronbach's alpha values exceeding 0.800, surpassing the recommended threshold of 0.7 (Nunnally & Bernstein, 1994).

Additionally, the composite reliability (CR) calculated for all factors is above 0.900, suggesting high reliability according to the recommendations of Hair et al. (2010).

Convergent validity was verified by calculating the average variance extracted (AVE),

Tab. 3: Assessment of model reliability and validity

Construct	Loading
Programmed behavior (Cronbach's alpha = 0.870; CR = 0.940; AVE = 0.566)	
PB1	0.796
PB2	0.725
PB3	0.769
PB4	0.826
PB5	0.779
PB6	0.729
PB7	0.624
Unprogrammed behavior (Cronbach's alpha = 0.815; CR = 0.937; AVE = 0.510)	
UB1	0.706
UB2	0.723
UB3	0.686
UB4	0.714
UB5	0.714
UB6	0.642
UB7	0.692
UB8	0.762
UB9	0.774
Responsible consumption (Cronbach's alpha = 0.868; CR = 0.937; AVE = 0.521)	
RC1	0.796
RC2	0.713
RC3	0.718
RC4	0.780
RC5	0.744
RC6	0.707
RC7	0.666
RC8	0.637
Food safety (Cronbach's alpha = 0.824; CR = 0.937; AVE = 0.521)	
FS1	0.692
FS2	0.728
FS3	0.642
FS4	0.706
FS5	0.693
FS6	0.717
FS7	0.706
FS8	0.815
FS9	0.715
FS10	0.721

Note: CR – composite reliability; AVE – average variance extracted.

Source: own

which exceeded 0.5. Since the threshold of 0.5 proposed by Fornell and Larcker (1981) is surpassed, this indicates that the construct explains an adequate proportion of the variance in its items. In conclusion, the results support the reliability and convergent validity of the construct used in this study.

Discriminant validity needs to be verified to ensure that a construct has greater variance with its own measures compared to other constructs. To pass this test, the square root of AVE must be greater than the correlation between the construct and any other construct (Fornell & Larcker, 1981). The results in Tab. 4 demonstrate that discriminant validity is met, and thus it can be concluded that the model satisfies the requirements for reliability and validity. Discriminant validity needs to be verified to ensure that a construct has greater variance with its own measures compared to other constructs.

To pass this test, the square root of AVE must be greater than the correlation between the construct and any other construct (Fornell & Larcker, 1981). The results in Tab. 4 demonstrate that discriminant validity is met, and thus it can be concluded that the model satisfies the requirements for reliability and validity.

Tab. 4: Assessment of discriminant validity (Fornell-Larcker criterion)

	Programmed behavior	Unprogrammed behavior	Responsible consumption	Food safety
Programmed behavior	0.752	0.316	0.366	0.620
Unprogrammed behavior	0.316	0.714	0.676	0.311
Responsible consumption	0.366	0.676	0.722	0.368
Food safety	0.620	0.311	0.368	0.722

Source: own

Tab. 5: Summary of the structural model analysis

Hypothesis			Coeficient β	*p*-value	Decision
Programmed behavior	<---	**Age**	0.163	0.006	*H1* is validated
Programmed behavior	<---	**Sex**	0.172	0.049	*H1* is validated
Unprogrammed behavior	<---	**Age**	0.105	0.006	*H2* is validated
Unprogrammed behavior	<---	**Sex**	−0.061	0.259	*H2* is not validated
Food safety	<---	**Studies**	−0.068	0.105	*H4* is not validated
Food safety	<---	**Income**	−0.133	0.000	*H4* is validated
Food safety	<---	**Age**	−0.089	0.054	*H4* is validated
Food safety	<---	**Sex**	0.034	0.618	*H4* is not validated
Programmed behavior	<---	**Studies**	−0.090	0.094	*H1* is not validated
Programmed behavior	<---	**Income**	−0.016	0.748	*H1* is not validated
Responsible consumption	<---	**Studies**	−0.035	0.573	*H3* is not validated
Unprogrammed behavior	<---	**Income**	−0.051	0.100	*H2* is not validated
Unprogrammed behavior	<---	**Studies**	−0.013	0.694	*H2* is not validated
Responsible consumption	<---	**Sex**	−0.037	0.715	*H3* is not validated
Responsible consumption	<---	**Age**	0.224	0.001	*H3* is validated
Responsible consumption	<---	**Income**	0.009	0.880	*H3* is not validated

Source: own

3.3 Structural model analysis

To test the hypotheses, a structural model analysis was performed. This model was used to determine the effect of demographic variables on different types of consumer behavior. Tab. 5 summarizes the analysis conducted through the structural model.

The structural model allowed for the delineation of the two consumption patterns: adopting responsible consumption and prioritizing food safety through the purchase of health-safe goods. The results highlight the alignment of each consumption pattern with a specific behavior observed in the food market, whether it involves programmed or unprogrammed behavior, conscious or less conscious actions, and motivated or unmotivated choices.

Tab. 5 validates or invalidates the formulated hypotheses in relation to the demographic factors analysed. Within the scope of the research, the age of respondents emerged as the relevant factor that can trigger or influence a particular behavior or consumption pattern. This finding reflects the constant pressure consumers face in balancing the interplay between needs and rationality versus emotions and experiences.

The model was estimated using structural equation modelling based on the partial least squares method in SmartPLS 4.0 (Fig. 1). The schematic representation succinctly illustrates the relationships between programmed or unprogrammed behavior and the two consumption patterns: responsible consumption and consumption driven by interest in food safety.

In the food market, consumers can adopt complex purchasing behaviours, including habitual behaviours based on past experiences, or behaviours focused on diversity and the desire to try something new and gain a specific experience.

Alternatively, they may exhibit impulsive, unplanned behaviours influenced by emotions or moods. This context encompasses both programmed and unprogrammed behaviours. To analyse these dynamics, three hypotheses were formulated to assess whether the two factors (experimental consumption and information sources) impact consumer preferences.

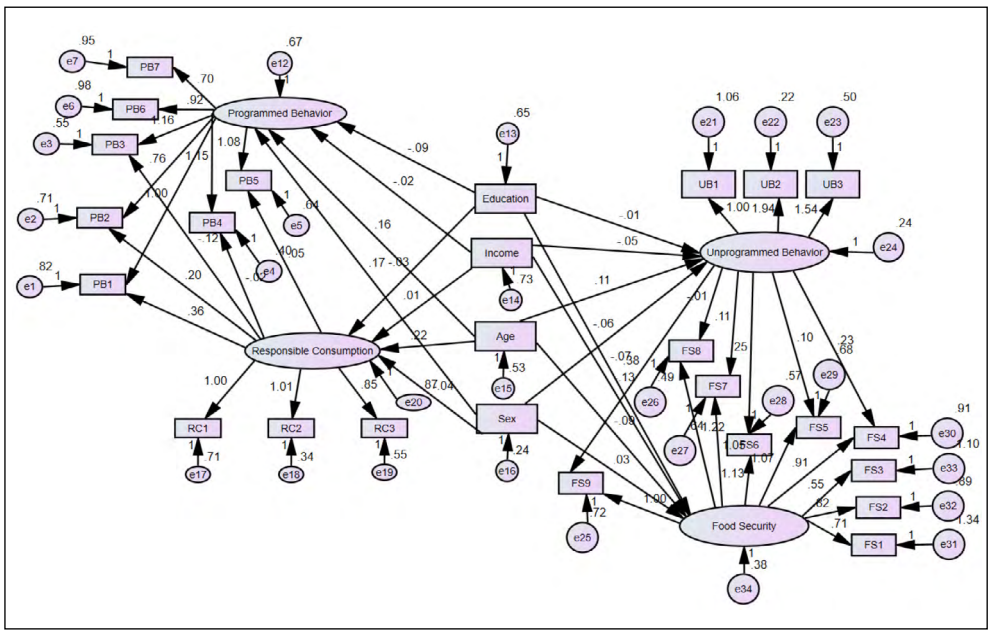

Fig. 1: Structural model of consumer behavior

Source: own

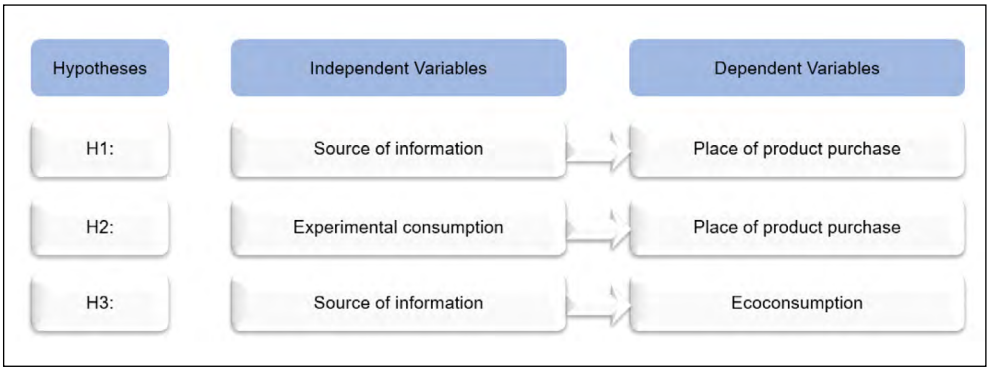

Fig. 2: Hypotheses proposed

Source: own research

Information sources are directly linked to the place of product purchase. Experimental consumption depends on the location of product acquisition. Information sources influence eco-consumerism among consumers. These hypotheses are summarized in Fig. 2.

H1: The impact of demographic factors on programmed behavior.

The first hypothesis focuses on the influence of demographic factors on programmed behavior, which is primarily driven by a specific consumer need. The analysis highlights two key findings: programmed behavior is positively influenced by both age and gender, while income and education do not play a role in decisions related to food product choices. Programmed behavior, being conscious and motivated, is shaped by prior learning. Age emerges as a relevant factor, as purchasing decisions increasingly rely on personal experiences, voluntary mechanisms, and rationality as consumers grow older. Similarly, gender plays a significant role, with women forming the predominant purchasing segment in Romanian households. Income and education are not major factors in programmed purchasing decisions, as these are cantered on rationality and immediate needs. Additionally, previous experiences heavily influence preferences and purchasing behavior.

The hypothesis was validated by the study.

H2: The impact of demographic factors on unprogrammed behavior.

The second hypothesis reveals that unprogrammed behavior is positively influenced by age, while gender, income, and education do not significantly impact such behavior. A plausible explanation is that age increases the likelihood of impulsive purchases driven by emotions, moods, and a desire for novel experiences. However, gender, income, and education are not practical determinants in impulsive purchases, which characterize unprogrammed behavior.

The hypothesis was validated by the study.

H3: The impact of demographic factors on responsible consumption.

The third hypothesis aims to identify determinants in the manifestation of a responsible consumption pattern, shaped by recent shifts in consumer attitudes. The results show that age positively influences responsible consumption, while gender, education, and income have no significant impact. Responsible consumption, focused on saving rather than consumerism, develops over time, with age being a key criterion. The hypothesis highlights segments of consumers who avoid food waste, make shopping lists, and prefer quality goods and local products, often driven by experience and time.

The hypothesis was validated by the study.

H4: The impact of demographic factors on food safety.

The fourth hypothesis expresses consumers' concerns about food safety under the influence of demographic factors. The model shows

that age and income negatively influence food safety, while gender and education have no effect. While food safety concerns typically increase with age, this was not validated in the study. Similarly, lower-income segments show an early interest in nutrition and food safety. Thus, negative influences of age and income on food safety are partially supported.

The hypothesis was not validated by the study (Tab. 5).

H5: The impact of experimental consumption and information sources on consumer preferences and adopting a consumption pattern over time.

The fifth hypothesis aimed to explore how experimental consumption and information sources shape consumer preferences and influence the adaptation of the food supply chain. The hypothesis suggested that novelty-driven or experimental consumption and the sources of information could play significant roles in shaping choices and adapting food consumption patterns.

The hypothesis was not validated by the study (Tab. 5).

Applying the Chi-square test for the first three hypotheses reveals the following. This nonparametric method, suitable for assessing relationships between categorical variables, was applied in accordance with methodological recommendations from Agresti (2013) and Siegel and Castellan (1988), who emphasize its relevance in behavioral data analysis when parametric assumptions are not met. The results indicate that *H1* and *H3* show weak relationships between variables, while *H2* demonstrates a moderate relationship. These results suggest that the first three hypotheses are supported to varying degrees (Tab. 6).

Tab. 6: Hypotheses testing using the Chi-square statistics

Hypothesis	Chi² (*p*-value)	Cramer's V	Decision
H1	0.015	0.138	Supported
H2	0.000	0.208	Supported
H3	0.000	0.177	Supported

Source: own

The study provides valuable insights into the dynamics of programmed and unprogrammed behaviors, responsible consumption, and the impact of demographic factors. However, further research is required to explore additional determinants and broader population samples for deeper analysis.

All three formulated hypotheses are validated through the conducted tests, confirming the importance of information sources in determining the place of purchase. The development of commerce has led to the emergence of c-stores that offer practical and quick consumption solutions to the population, supporting the rise of convenience food consumption. Key drivers of this behavioral trend include urban agglomerations, fast-paced lifestyles, time constraints, shopping ease, and the speed of commercial services. Additionally, the wellness trend (physical, mental, and social well-being) has increased the demand for fresh foods alongside the growth of ready-to-eat food options that can be consumed on the go, meeting the rapid needs of time-constrained consumers. In the initial phase, consumer behavior is driven by novelty or curiosity (experimental consumption), followed by experience-based consumption, which transitions into conscious and programmed behavior.

Secondly, experimental consumption is influenced by the place of purchase, as buying actions are often driven by the novelty of products or curiosity and focus on establishing interpersonal connections. Initially, this reflects impulsive, unplanned purchases driven by emotions or moods during interactions with sales spaces or commercial staff. Over time, these behaviors may evolve into conscious and programmed consumption based on past experiences.

Thirdly, information sources and recommendations from other consumers influence the selection process in the food market.

A notable consumption pattern emerging during the pandemic allowed consumers to reconsider their lifestyles and the implications of their choices on the environment and the local economy. The rise of eco-consumerism brought a long-term behavioral shift, describing an ethical and responsible consumer who initiates motivated and conscious purchasing acts, aligning with programmed behavior. The pandemic significantly impacted the socio-economic environment, altering behaviors, attitudes, consumption patterns, and lifestyles. Consequently, food market actors (retailers and suppliers) must adapt to market demands and comply with a more conscious and motivated consumer behavior, driven by more demanding population segments with higher consumption standards.

In the agri-food market, besides the policies and strategies already applied at the European level and translated into practice, system actors must be prepared to adapt to increasingly discerning and unpredictable consumer demands. This requires innovative approaches from both producers and retailers, as Romanian consumers are now more aware of prices, quality, and living standards, as well as the importance of being informed about food products that meet their specific needs at a given time and place.

Adapting the entire food supply chain to new business models involves significant investment efforts to provide consumers with valuable and personalized food experiences.

Key strategic directions:

i) Encouraging responsible consumption: actively promoting local producers and domestic products, avoiding products with excessive packaging;

ii) Focusing on safe, healthy, and organic products: providing affordable eco and bio options, conducting awareness campaigns on labeling and product traceability, increasing the range of green products sold under private labels at accessible prices;

iii) Launching educational campaigns: addressing nutrition and healthy eating habits;

iv) Initiating volunteer actions: aimed at reducing food waste and developing sustainable, long-term dietary practices;

v) Emphasizing social commerce: catering to consumers who prioritize experiences over products by expanding product ranges, personalizing the shopping experience through active communication and feedback, and employing manipulative marketing tactics to boost sales across the food supply chain.

Additionally, personalizing assortments, integrating e-commerce into business models, and offering delivery services will ensure greater flexibility for retailers. These efforts will enable the development of new commercial space formats through the remodeling of business strategies, helping retailers attract new consumer segments.

Conclusions

Rethinking the commercial system and adopting new business models and practical consumption solutions guide the efforts of commercial actors towards offering valuable and personalized food experiences to consumers. Trends in food markets, innovation, and the development of smart technologies will enable a better understanding of consumer behaviors and preferences at the current stage of food market development.

Based on these considerations, the paper aims to highlight specific purchasing and consumption habits from the perspective of how consumers relate to their environment, which influences their choices and changes their economic behavior. The importance of this research lies in its approach to the consumption patterns observed in the post-pandemic era, considering the multitude of factors that influence purchasing decisions and choices, as well as how these patterns integrate into programmed or unprogrammed behavior.

Practical significance is represented by the way variables are presented, which allowed for the shaping of certain consumption patterns within the agri-food market. The research also had limitations, given the relatively small number of respondents and the complexity of the issues addressed compared to behavioral analyses conducted in other markets over time. If the research results are compared to the diversity of approaches within the food market, the methodology and description used in this study represent a valuable addition to the specialized literature.

Future research will develop a more detailed analysis of how other determinants can modify and influence purchasing and consumption behaviors, as well as conduct evolutionary comparisons to identify the emergence of other consumption patterns in the food market. This research could integrate a broader

range of information deliverables that comprehensively describe the food market and help outline consumer and retailer profiles at the national level.

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Exploring digital competence's impact on faculty well-being through SEM-SVM analysis

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Abstract: *This research aims to explore the impact of digital teaching competence on faculty career well-being, teacher self-efficacy, and the moderating role of pedagogical content knowledge within the context of colleges in Pakistan. A quantitative approach was adopted, involving 266 faculty members from various academic programs in colleges across Pakistan. Data were collected through an online survey using validated scales adapted from prior research. The study used partial least squares structural equation modeling (PLS-SEM) to analyze the relationships between constructs. Support vector machine (SVM) analysis was conducted using JASP software to enhance predictive accuracy and identify the importance of key features in the dataset. The results confirm that digital teaching competence significantly impacts faculty career well-being and teacher self-efficacy. Teacher self-efficacy mediated the relationship between digital teaching competence and faculty career well-being, providing deeper insights into this linkage. Furthermore, pedagogical content knowledge moderated the effect of digital teaching competence on faculty career well-being, emphasizing its critical role. The inclusion of SVM analysis revealed the significance of variables such as psychological factors and AI exposure in influencing predictive performance, further validating the robustness of the findings. This study contributes to the existing literature by demonstrating the critical role of digital teaching competencies in enhancing faculty members' well-being and effectiveness. It underscores the need for targeted professional development programs that integrate technology and pedagogy, ultimately fostering a more supportive educational environment for faculty and improving overall teaching quality.*

Keywords: *Digital teaching competence, teacher self-efficacy, pedagogical content knowledge, faculty career well-being, support vector machine.*

JEL Classification: *I23, J24, O33.*

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Introduction

The integration of digital technologies in education has transformed faculty roles in institutions of higher learning, and new teaching and learning practices become more prominent. Effective pedagogy requires a faculty member who is competent in digital teaching, which enables him to use technology to engage and facilitate student learning outcomes (Yang & Du, 2024). The shifting educational landscape has made it essential to respond to the plethora of needs that have emerged in response to digital education; faculty members' digital competencies are among them (Nousheen et al., 2024). The transformation thus calls for an inclusive comprehension of how digital teaching competency affects the various aspects of educators' professional lives (Kruskopf et al., 2024), such as well-being and self-efficacy (Martinsone & Vanaga, 2024). Therefore, studying the relationship between digital teaching competence, teacher self-efficacy, and faculty career well-being is essential in addressing the challenge of modern education.

Research has described the interaction between digital teaching competence, teacher self-efficacy, and faculty well-being (Khan et al., 2022; Valle et al., 2024). For instance, it has been found that educators who possess digital literacy and competency in digital tools have a higher sense of self-efficacy, hence enhancing their instructional delivery (Valle et al., 2024). In addition, research suggests that higher self-efficacy is positively associated with faculty career well-being because the faculty's confidence in their employability skills will increase their affection for their job (Orakova et al., 2024). In addition, different findings have been made that digital teaching competency may lead to better pedagogical strategies and, therefore, contribute to an effective supportive learning climate that increases the professional satisfaction of educators (Lee et al., 2024). In light of this, the studies outline how digital competency impacts educators' career experiences and outcomes (Leino et al., 2024). Moreover, research studies indicate that faculty members who are highly digitally literate have better command over their workplace and are more adaptable to the nature of changing educational settings, which may lead to better career well-being (Gordon et al., 2024). This literature is of the same sort where the authors highlight the importance of digital skill development to safeguard professional identity and mitigate burnout among the staff (Nissim & Simon, 2024).

The complete understanding of the effects of digital teaching competence on faculty careers, however, is limited by the gap in the literature (Boeve-De Pauw et al., 2024). There needs to be more research investigating potential interactions between teacher self-efficacy or pedagogical content knowledge and digital teaching competence about faculty outcomes (Ghazali et al., 2024; Khan et al., 2022). Although the benefits of digital competence per se are as evident as the daylight, digital competence's role in moderating or mediating other variables in influencing faculty well-being remains unexplored (Täschner et al., 2024). Also, most publications focus on elementary or secondary school teachers, while college and university teachers hardly receive attention (Liu et al., 2024). Such a vast gap persists about how college faculty members manage challenges from digital teaching and how this would affect their job satisfaction (Šimunović et al., 2024). Additionally, few studies have used longitudinal research to analyze the long-term effects of digital competencies on faculty's well-being, thus limiting the extent to which time-evolving changes in the impact of digital literacy can be captured (Ninković et al., 2024). These gaps would be filled so faculty career well-being and digital teaching competency could better understand the subtle interrelationships between these factors (Ali et al., 2024).

To establish a credible motivation towards this research, there is a need to discover the growing importance of digital competence in higher education, particularly regarding the driving forces of accelerated technological change and pedagogical innovation. This drift towards digital learning environments has raised unprecedented challenges for academics to develop digital teaching competence to maximize their performance and overall career well-being. Despite increasing interest in the digitalization of education, a critical knowledge gap exists regarding the impact of digital teaching competence on faculty career wellness and self-efficacy. Theoretical frameworks provide a foundation for this research. Bandura's social cognitive theory focuses on the role of self-efficacy in triggering behaviors, suggesting that staff with greater digital capabilities will be more likely to possess higher self-efficacy

and, consequently, improved career success (Kholifah et al., 2023). The technology acceptance model also focuses on perceived ease of use and usefulness as the primary drivers of technology adoption. Faculty members who view digital teaching tools as helpful are more likely to use them successfully in their pedagogy, which contributes to greater job satisfaction and career well-being (Wang & Chu, 2023).

Based on these theoretical foundations, this research aims to address significant research gaps by investigating the impact of digital teaching competency on faculty career happiness and self-efficacy. Moreover, it also explores teacher self-efficacy as a mediating variable and pedagogical content knowledge as a moderator of this relationship. As opposed to past studies isolating these variables, this paper is an interdisciplinary study that helps in understanding how these relationships take place in a university setting. Through this process, it provides new insights about how faculty members can leverage digital competencies so as to grow more professionally engaged and productive. Secondarily, the paper contributes to general technology-enhanced learning literature by grounding faculty development strategies by institutions with empirical evidence. To ensure fundamental clarity and coherence, the paper is organized as follows: after the introduction is a review of theory and methodology germane to the research, followed by methodology outlining data collection and analysis processes. It is followed by a section of findings, which are then interpreted within the framework of theory and practice implications. Lastly, the research ends with future research directions and limitations, presenting potential avenues for further research in this critical field.

1 Theoretical background

Education for well-being emphasizes the holistic development of students, focusing not only on academic achievements but also on emotional, social, and mental health aspects (Wong et al., 2023). Research highlights faculty members' pivotal role in shaping this comprehensive educational experience (Lekhu, 2023). Faculty are increasingly recognized as key facilitators in promoting well-being through direct instruction and creating supportive learning environments (Uçar & Zarfsaz, 2023). Studies have shown that when educators incorporate well-being frameworks into their teaching, students exhibit higher engagement, resilience, and self-awareness levels. These frameworks often promote positive relationships, mindfulness, emotional intelligence, and problem-solving skills (Zheng et al., 2023). Faculty members can help cultivate a culture of care and empathy through their interactions and instructional strategies, which is crucial for students' development. This enhances student outcomes and fosters a positive educational climate that benefits learners and educators (Göbel et al., 2023).

Additionally, research has highlighted the importance of faculty well-being in achieving these educational goals (Su, 2023). Educators who experience high levels of job satisfaction, emotional support, and professional development opportunities are more likely to engage in practices that promote student well-being (Chen, 2023). Faculty well-being directly influences their teaching effectiveness, ability to connect with students, and resilience in managing classroom challenges. Educational institutions prioritizing their faculty's well-being often see a trickle-down effect, where empowered and supported teachers create more inclusive and supportive classrooms (Sehar & Alwi, 2023). Literature in this domain underscores the need for systemic changes, advocating for policies integrating well-being into educational curricula and providing continuous support for educators (Rastegar & Rahimi, 2023). This dual focus on faculty well-being and the well-being of students forms the cornerstone of a sustainable and nurturing educational ecosystem.

Therefore, studies have found that digital teaching capabilities are an essential predictor of faculty career well-being (Hershkovitz et al., 2023). The research has established that such faculties would enjoy greater job satisfaction, less stress, and higher overall well-being with greater digital teaching capabilities (Guoyan et al., 2023). For instance, research has found that digitally literate teachers often have a positive attitude toward their teaching context and are much more actively engaged in their practice (Masoumi & Noroozi, 2023). Faculty members who use technology effectively in their teaching practices are most frequently characterized by much higher job satisfaction and improved well-being (Shu, 2022). In addition, studies have shown a relationship between digital competence and professional development opportunities, so it is more likely

that these faculties who invest time in developing their digital competencies will have their career paths well-supported (Liang et al., 2022). Based on these findings, digital teaching competence is a crucial factor influencing faculty career well-being (Shonfeld et al., 2022). The improving digital competencies for educators help them to develop more security and self-confidence in their pedagogy, and changes in the educational landscape become more amendable for them (Liu et al., 2022). Indeed, some of these changes can alleviate inadequacy and frustration among educators needing help using digital materials (Zhang & Fang, 2022). Empirical evidence also suggests that developing digital competencies enhances teaching quality and a collaborative, innovative educational climate, which maximizes welfare among faculty staff (Yang & Du, 2024). It is a reasonable suggestion to advance that higher digital teaching competence positively correlates with the better career well-being of faculty members.

H1: Digital teaching competence significantly influences the faculty's career well-being.

However, many scholars have researched the effects of digital teaching competency on a teacher's self-efficacy, focusing only on how technology shapes an educator's confidence in performing his or her job (Kruskopf et al., 2024). According to studies, teachers with more experience working with digital tools display relatively higher self-efficacy beliefs in the probability of effective instruction and interaction with students (Valle et al., 2024). For example, research findings showed that training and resource aid for instructors to develop their digital skills enhance the self-efficacy level of instructors in instructional effective practices and subsequent learning results (Lee et al., 2024). Empirical evidence also proves that digitally more competent teachers are typically intrinsically innovative in educational change, which drives and verifies their self-efficacy belief in being a good teacher (Gordon et al., 2024). Having established the nexus between digital teaching competency and self-efficacy, it becomes feasible to hypothesize that there is a significant relationship between the two constructs (Boeve-De Pauw et al., 2024). The more the teacher develops his digital skills, the more adept he becomes with different teaching situations and thus would be imbued with mastery over his teaching practice (Täschner et al., 2024). This mastery will likely be translated into improved self-efficacy, allowing the teacher to exercise higher confidence when discharging his or her role (Šimunović et al., 2024). In addition, empirical research points out that instructor self-efficacy goes hand in hand with instructional quality and, therefore, in any case, attests to the fact that developing digital competence would be beneficial not only to individual instructors but also to enhance student learning experiences (Ali et al., 2024). At this point, it can be feasible to point out that instructional self-efficacy relies significantly on digital teaching competence.

H2: Digital teaching competence significantly influences teacher self-efficacy.

Some research has been directed to the mediating effect of instructor self-efficacy on learning outcomes (Wang & Chu, 2023). Research studies have shown that self-efficacy facilitates turning skills and competencies into positive career experiences (Lekhu, 2023). Research findings on digital teaching competencies indicate that teachers with high self-efficacy will facilitate better and more effective implementation of technology in class, significantly improving teaching practices and satisfaction with their careers (Lekhu, 2023). Empirical results indicate that self-efficacy influences educators' resilience and adaptive strategies to overcome digital instruction challenges (Zheng et al., 2023). The interplay points out that self-efficacy is not a byproduct of digital competence but rather a mediating variable of crucial influence on the relationship between digital teaching skills and overall career well-being (Su, 2023). This relationship, found in established studies between digital teaching competence and teacher or faculty career well-being self-efficacy, makes it reasonable to propose that self-efficacy significantly mediates the relationship between digital teaching competence and faculty career well-being (Hershkovitz et al., 2023). As educators develop digital skills, their self-efficacy will probably increase, positively affecting their career well-being (Masoumi & Noroozi, 2023). Empirical evidence indicates that teachers with high self-efficacy are more challenging to face, look for professional development opportunities, and have a positive future vision for their careers (Liang et al., 2022). Therefore, it can be an agency connecting the development

of digital teaching competency to faculty career well-being, underlining why it is very relevant in this relation.

H3: Teacher self-efficacy significantly mediates the relationship between digital teaching competence and the faculty's career well-being.

It has been widely realized through research that pedagogical content knowledge PCK is a significant part of effective pedagogical practices (Liu et al., 2022). Research reveals that teachers who possess a proper idea about pedagogy and content are much more capable of embedding digital learning tools in the learning process (Nousheen et al., 2024). This integration will facilitate more profound learning experiences to enhance faculty career well-being (Martinsone & Vanaga, 2024). For example, empirical evidence indicates that such teachers, being more PCK-oriented, are likely to use technology in proper educational ways, yielding healthier results for students and improved job satisfaction for teachers (Orakova et al., 2024). Moreover, research evidence has revealed that PCK is an important factor in determining teachers' resistance, readiness, and adaptation to new technologies, and these can, in turn, further enhance teachers' confidence and well-being within jobs (Leino et al., 2024). Based on such findings, one can hypothesize that pedagogical content knowledge significantly moderates the relationship between the level of digital teaching competence and the extent of faculty career well-being (Nissim & Simon, 2024). Faculties with high levels of PCK are likely to use digital competencies much more effectively, improving their practice and leading to better career experiences (Ghazali et al., 2024). This would imply that, in theory, the better the educators' digital skills and more profound pedagogical knowledge, the better the environments they would create, which favor well-being (Liu et al., 2024). Moreover, PCK may act as a buffer against all the digital instruction stressors, allowing faculty members to tackle the challenges more resiliently (Ninković et al., 2024). This leads to the plausibility of stating that PCK plays a critical moderating role in the relationship between digital teaching competence and faculty career well-being, modifying how educators experience their professional roles in this technology-rich landscape.

H4: Pedagogical content knowledge significantly moderates the relationship between digital teaching competence and teacher self-efficacy.

The proposed model of the study was derived from the previous literature, and shown in Fig. 1.

2 Research methodology

2.1 Research design

The study used a quantitative research design to examine the interrelationship between

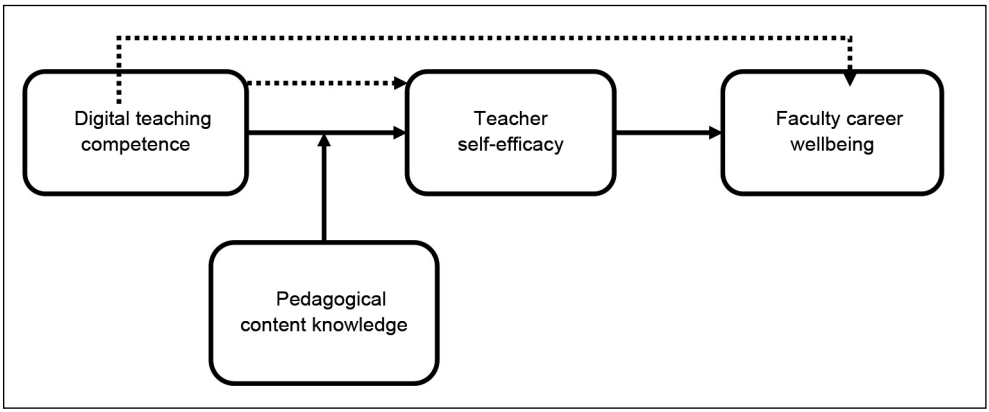

Fig. 1: Proposed model of the study

Source: own

digital teaching competence, lecturers' career well-being, teachers' self-efficacy, and pedagogical content knowledge about colleges within Pakistan. By applying established scales for measuring such constructs, this study provided empirical insight into how digital competencies impact lecturers' perceptions of their overall well-being and self-efficacy. Participants: this paper targeted lecturers who teach at various academic programs in colleges in various parts of Pakistan. A total of 266 respondents participated in this research. Stratified random sampling, whereby fair representations from various disciplines and different programs within the colleges were ensured, was adopted to select participants. An online questionnaire was sent through email and academic networks to involve everyone. The survey tool aimed to gather information regarding digital teaching competence, career well-being, self-efficacy, and pedagogical content knowledge regarding the faculty. The questionnaire included demographic questions to gather fundamental participant characteristics, such as age, gender, academic rank, and the years experienced in teaching.

2.2 Scales of measurement

The measurement scales used for this study were adopted from previous empirical research work for reliability and validity. Items that were used to measure established constructs were of proven psychometric properties. Digital teaching competence was measured through items that would evaluate the proficiency of faculty members with digital tools and technologies used in their teaching work. Faculty career well-being would be measured through items meant to capture job satisfaction, work-life balance, and overall professional fulfillment. Teacher self-efficacy was measured by faculty responses regarding the level of confidence attached to teaching skills and the ability to improve engagement. Lastly, pedagogical content knowledge was assessed using items mainly focused on integrating subject matter knowledge with practical strategies for teaching. Each item received ratings from a Likert scale that ranged from 1, where the respondents strongly disagreed with the given statement, to 5, which reflected an intensely agreeable response. Tab. 1 shows the items of questionnaire and measurements.

Tab. 1: Questionnaire and measurements

Construct	Items	References
Digital teaching competence	Five	Chu et al. (2023)
Teacher self-efficacy	Thirteen	Liu et al. (2023)
Pedagogical content knowledge	Six	Mensah (2023)
Faculty career well-being	Eight	Liu et al. (2023)

Source: own

2.3 Estimation techniques

Partial least squares structural equation modeling (PLS-SEM) is a robust statistical technique for examining complex relationships between variables. PLS-SEM was chosen because it can also use relatively small samples and provide insights into the measurement and structural models (Ahmed et al., 2024). The procedure adopted in this study consisted of two primary stages: the initial assessment of the measurement model and the structural model's evaluation. Measurement model – the reliability and validity of the scales were considered. Reliability assessment was taken from Cronbach's alpha and composite reliability coefficients, while the measures that follow established validity criteria were presented with average variance extracted (AVE). Discriminant validity was measured using the Fornell-Larcker criterion and the heterotrait-monotrait ratio HTMT. The next step was that after the validation of the measurement model, the structural model was tested to evaluate relationships between the constructs as hypothesized. Path coefficients, *T*-statistics, and *p*-values were calculated to probe into the significance and strength of the relationships. In parallel,

R-square values were computed to determine the explained variance in the dependent variables. Further, it examines the mediating role of teacher self-efficacy and the moderating role of pedagogical content knowledge on the relationship of digital teaching competence with faculty career well-being.

Support vector machine analysis was further used by the software JASP to strengthen the robustness and predictiveness of the results. SVM was applied to classify and predict relationships between variables, providing a nonlinear way of modeling complex interactions. The JASP has been an intuitive implementation platform with detailed performance metrics – MSE, RMSE, and R^2. Feature importance metrics were used to determine the relative contribution of key factors such as psychological influences, AI exposure, and privacy assurances to the predictive model. This integration of SVM analysis complements the PLS-SEM approach by providing a more holistic understanding of the relationships in the dataset (Anwar et al., 2025).

3 Results and discussion

3.1 Reliability and validity statistics

Tab. 2 depicts the reliability and validity statistics of the variables that were examined in depth. Tab. 2 tabulates the Cronbach's alpha value of the constructs concerned, composite reliability (CR), and average variance extracted (AVE). Regarding digital teaching competence, Cronbach's alpha is 0.889, and CR is 0.905, thus measuring exceptionally high constructs' internal consistency and reliability. The AVE of 0.661 presents a great capture of the variance in DTC by the underlying items; hence, it satisfies the threshold often accepted at 0.5 for convergent validity.

Staff career well-being also shows good reliability with Cronbach's alpha at 0.847 and composite reliability of 0.892, apart from an AVE of 0.623, proving it to be valid and implying one may possess a high level of correlation among its measurement items. Comparatively lower reliability also lies in pedagogical content knowledge with Cronbach's alpha of 0.809 and composite reliability of 0.862. Yet, the AVE of 0.513 is above the minimum threshold for convergent validity. Lastly, teacher self-efficacy (TSE) shows great reliability with Cronbach's alpha of 0.940 and composite reliability of 0.949, and an AVE of 0.591. It is great to observe such high reliability: responses to nearly all items are stable in terms of their correlation with teacher self-efficacy, which supports that the items capture the construct.

3.2 Measurement items' fitness statistics

Tab. 3 presents measurement items' fit statistics relative to the constructs relevant to each in this research. The loadings of every item indicate how much they contribute to the constructs, with the higher values indicating higher relationships. It is apparent that digital teaching competence items DTC1, DTC3, and DTC5 have high loadings of 0.818, 0.875, and 0.938, respectively, which indicate a high contribution towards this construct. Conversely, DTC2 loads low at 0.606 and thus is not thought to make a significant contribution towards overall constructs and warrants further exploration. Items measuring the career well-being of the faculty, FCW4 (0.721) and FCW8 (0.890), reflect a high representation of this construct, and other items in FCW5 (0.821) and FCW6 (0.765) also reflect high contributions. From the PCK factor, items' loading also differed from item to item with varying levels of significance strength. The strongest is PCK3 with 0.841 value, followed by PCK1

Tab. 2: Variables reliability and validity

	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)
Digital teaching competence	0.889	0.905	0.661
Faculty career well-being	0.847	0.892	0.623
Pedagogical content knowledge	0.809	0.862	0.513
Teacher self-efficacy	0.940	0.949	0.591

Source: own

at 0.753. But PCK4 shows relatively weaker loading of 0.616; thus, this will weaken the overall strength of this construct. Teacher self-efficacy demonstrates a more stable performance, with loadings predominantly above 0.700, and this means that items such as TSE11 (0.882) and TSE8 (0.845) are contributing significantly. The variation in the range of loadings for the different constructs captures that most items are well performing in their categories. There are some items, such as DTC2 and PCK4, and others, such as DPC3 or TPK10, that need to be re-evaluated to enhance the overall measurement model. This analysis validates that the selected items accurately measure the constructs of interest and hence validates the study.

Tab. 3: Measurement items fitness statistics

	Digital teaching competence	*Faculty career well-being*	*Pedagogical content knowledge*	*Teacher self-efficacy*
DTC1	0.818			
DTC2	0.606			
DTC3	0.875			
DTC4	0.789			
DTC5	0.938			
FCW4		0.721		
FCW5		0.821		
FCW6		0.765		
FCW7		0.738		
FCW8		0.890		
PCK1			0.753	
PCK2			0.757	
PCK3			0.841	
PCK4			0.616	
PCK5			0.667	
PCK6			0.640	
TSE1				0.681
TSE10				0.804
TSE11				0.882
TSE12				0.829
TSE13				0.786
TSE2				0.735
TSE3				0.600
TSE4				0.712
TSE5				0.843
TSE6				0.624
TSE7				0.713
TSE8				0.845
TSE9				0.869

Note: DTC – digital teaching competence; FCW – faculty career well-being; PCK – pedagogical content knowledge; TSE – teacher self-efficacy.

Source: own

3.3 Fornell-Larcker criterion for discriminant validity

Tab. 4 shows the Fornell-Larcker criterion for determining discriminant validity amongst the study constructs. The diagonal elements are the square root of the AVE for each construct, while off-diagonal elements represent the correlation between a pair of constructs. For DTC, the square root of AVE is 0.813, which suggests that it has good discriminant validity because it is above its correlations with other constructs. The same applies to faculty career well-being, which yields an AVE value of 0.789, again above the correlations it has with other constructs, affirming the distinctiveness of the two constructs. The correlation between DTC and FCW is relatively low at 0.183, indicates that although there may be some relationship, they are distinct constructs. Pedagogical content knowledge (PCK) has a square root of AVE of 0.717. This would sustain its discriminant validity since it is higher than its correlations with other constructs, especially with FCW at 0.532 and teacher self-efficacy at 0.319. Teacher self-efficacy has an AVE of 0.768. Its correlations with the two foregoing constructs are 0.792 with FCW and 0.842 with PCK. Though TSE has a more significant correlation with these constructs, the square root of AVE of TSE remains greater than these correlation values, thereby showing that it maintains its discriminant validity. In summary, by the Fornell-Larcker criterion, all constructs depict the value of being different and apart from one another, which adds further validation to the measurement model used in this study.

3.4 Heterotrait-monotrait ratio (HTMT)

Tab. 5 reports the heterotrait-monotrait ratio (HTMT) as a supplement for the discriminant validity of the constructs. For this table, lower values signify that discriminative validity is more appropriate, and values close to or higher than 0.85 signify it could be too high. The HTMT values of digital teaching competence about other constructs are low (the maximum is 0.165 with pedagogical content knowledge and 0.138 with faculty career well-being), which also provides clear differentiation between DTC and other variables. These values suggest that DTC is distinct from other constructs in this model. For FCW, the HTMT value with TSE is 0.842 and close to a commonly referenced threshold of 0.85. This indicates a robust relationship between the two constructs. Still, this does not eliminate discriminant validity; the HTMT ratio can show distinctiveness if viewed in conjunction with other validity measures. The HTMT

Tab. 4: Fornell-Larcker criterion

Variables	DTC	FCW	PCK	TSE
1. *Digital teaching competence*	0.813			
2. *Faculty career well-being*	0.183	0.789		
3. *Pedagogical content knowledge*	0.193	0.532	0.717	
4. *Teacher self-efficacy*	0.069	0.792	0.319	0.768

Source: own

Tab. 5: HTMT

Variables	DTC	FCW	PCK	TSE
1. *Digital teaching competence*				
2. *Faculty career well-being*	0.138			
3. *Pedagogical content knowledge*	0.165	0.632		
4. *Teacher self-efficacy*	0.102	0.842	0.384	

Source: own

value between PCK and TSE is at 0.384, which further supports the conclusion that, although related, the constructs used are reasonably distinct. Overall, the HTMT results reinforce the findings from the Fornell-Larcker criterion in that the constructs used in this research are adequately differentiated and legitimate in their inclusion in the model.

3.5 *R*-square statistics

Tab. 6 summarizes the *R*-square statistics and goodness-of-fit model statistics that serve to indicate to what degree constructs in the structural model are predicted. The values of *R*-square, thus, indicate the variance explained by the independent variable as a percentage of each dependent variable in the model. *R*-square values are also given for faculty career well-being with a strong value of 0.723, which means that the model can explain approximately 72.3% of the variation of faculty career well-being and hence shows that the predictor variables have a significant impact. Conversely, the *R*-square value for teacher self-efficacy stands at 0.115, where only 11.5% of its variance is explained by the independent variables in the model. Such an unequal variance explained by the model suggests that while faculty career well-being highly determines digital teaching competence, the predictors may explain just a limited amount of variance in teacher self-efficacy. Adjusted *R*-square estimates for FCW and TSE are 0.719 and 0.112, respectively. This reflects that the model still has robust predictive capability after adjusting for the number of predictor variables included in it. As the Q^2 predict is estimated at 0.066, the model holds predictive significance with respect to FCW since a change in the variable can be adequately predicted due to a change in the predictor variables. For TSE, no Q^2 predict value is given; this could be predictive irrelevance as predictors were unable to explain a minimum variance. The *R*-square statistics tend to be high, thus indicating good explanatory ability for FCW and indicating where additional research would be needed to elucidate other factors that make up TSE.

Tab. 6: *R*-square statistics model goodness of fit statistics

Variables	*R*-square	*R*-square adjusted	Q^2 predict	RMSE	MAE
Faculty career well-being	0.723	0.719	0.642	0.066	0.072
Teacher self-efficacy	0.115	0.112			

Source: own

3.6 *F*-square statistics

Tab. 7 summarizes the use of the *F*-square statistics in reporting effect sizes, indicating the effect of independent variables on the dependent variables along the model in any analysis. Such an effect size would be small, medium, or large at more than 0.15, 0.35, and 0.50, respectively. For faculty career well-being, the *F*-square value for digital teaching competence is 0.021, indicating a small effect size. This would mean that, although some contribution to variance in FCW is due to digital teaching competence, its effect magnitude is relatively modest. By contrast, PCK had a much more significant effect on FCW with an *F*-square value of 0.286, denoting a medium effect size. This means that PCK takes a more significant role in the career well-being of faculty, further emphasizing content knowledge besides digital skills. On the other hand, TSE, one of the elements, reveals that digital teaching competence has a more pronounced effect, the *F*-square value of 0.135 when interpreted as having a medium effect size. This would mean that increases in teacher self-efficacy are bound to result from increases in digital teaching competence. The *F*-square statistics do not explicitly report on the moderating effect of pedagogical content knowledge on TSE, which calls for further exploration in this area. Besides, the *F*-square value for TSE is sufficiently large at 1.552, which suggests the effect size is large, further indicating that the variations in self-efficacy are significantly influenced by other predictors within the model.

Tab. 7: ***F*-square statistics**

Variables	*Faculty career well-being*	*Teacher self-efficacy*
Digital teaching competence	0.021	0.135
Moderating effect of pedagogical content knowledge	0.018	
Pedagogical content knowledge	0.286	
Teacher self-efficacy	1.552	

Source: own

3.7 Path analysis results

Tab. 8 and Fig. 2 present the results of the path analysis, which examines the interactions among the main variables of this research. The 0.579 path coefficient, with *T*-statistic and *p*-value 7.906 and 0.000, respectively, indicates that digital teaching competence has a significant influence on faculty career well-being. Hence, this robust positive association means that the greater the development of digital teaching capabilities of a faculty member, the more his/her career overall well-being will be greatly influenced too. Additionally, it was also noted that teacher self-efficacy is heavily influenced by digital teaching competence; the path coefficient was calculated to be 0.369 and, the *T*-statistic was calculated as 4.855 and *p*-value = 0.000. This means that academic staff with digital teaching competencies have greater faith in their teaching.

In addition, the outcome also signifies an indirect positive relationship between digital teaching competencies and faculty career well-being with the mediator of teachers' self-efficacy, such that path coefficient = 0.448 and *T*-statistic = 6.816, *p*-value = 0.000. This has emphasized the role of teacher self-efficacy as a vital mediator, through which higher self-efficacy enhances the positive effect of digital competence on faculty well-being.

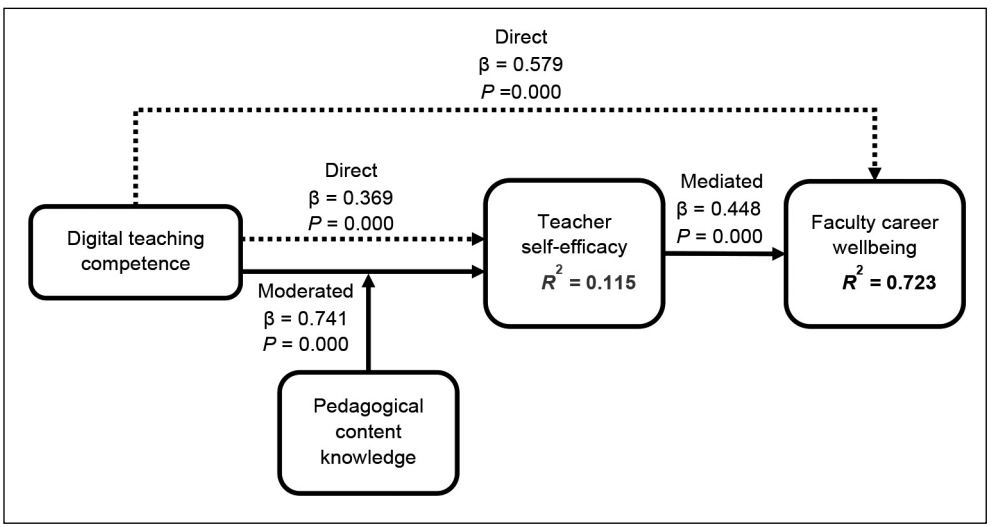

Fig. 2: **Structural model for path analysis**

Source: own

Tab. 8: Path analysis

Path analyses	Original sample	Sample mean	Standard deviation	*T*-statistics	*p*-values
Digital teaching competence significantly influences the faculty's career well-being.	0.579	0.687	0.087	7.906	0.000
Digital teaching competence significantly influences teacher self-efficacy.	0.369	0.475	0.080	4.855	0.000
Teacher self-efficacy significantly mediates the relationship between digital teaching competence and the faculty's career well-being.	0.448	0.454	0.059	6.816	0.000
Pedagogical content knowledge significantly moderates the relationship between digital teaching competence and teacher self-efficacy.	0.741	0.746	0.040	2.042	0.000

Source: own

Finally, the connection between digital teaching proficiency and teacher self-efficacy is greatly moderated by pedagogical content knowledge, as evidenced by the path coefficient of 0.741 and the *T*-statistic of 2.042 with *p*-value = 0.000. This would suggest that good pedagogical content knowledge reinforces the positive effects of digital teaching proficiency on faculty well-being thus it is a critical moderating variable. These results emphasize the interaction among digital teaching competence, self-efficacy, and pedagogical knowledge for promoting faculty well-being.

3.8 Performance metrics of the model

Tab. 9 gives the performance metrics of the model, which show the MSE (mean squared error) = 0.006. This means the average squared error between predicted values and actual values is 0.006. MSE scaled version of (MSE scaled) is 0.244. Therefore, this means that the value of the MSE is scaled to a range of 0.244. The RMSE (root mean squared error) is equal to 0.077. The square root of MSE measures the average difference between the predicted and actual values. MAE/MAD (mean absolute error/mean absolute deviation) is 0.064. This is the average absolute difference between the predicted and actual values. MAPE (mean absolute percentage error) is 13.72%. This is the average absolute percentage error between the predicted and actual values. *R*-squared (R^2) is 0.728, this implies that the model explained 72.8% of the change in the dependent variable.

3.9 Predictive power or performance plot

Fig. 3 displays the predictive power or performance plot of the model. The predicted values

Tab. 9: Model performance metrics

Performance metrics	Value
MSE	0.006
MSE (scaled)	0.244
RMSE	0.077
MAE/MAD	0.064
MAPE (%)	13.720
R^2	0.728

Source: own

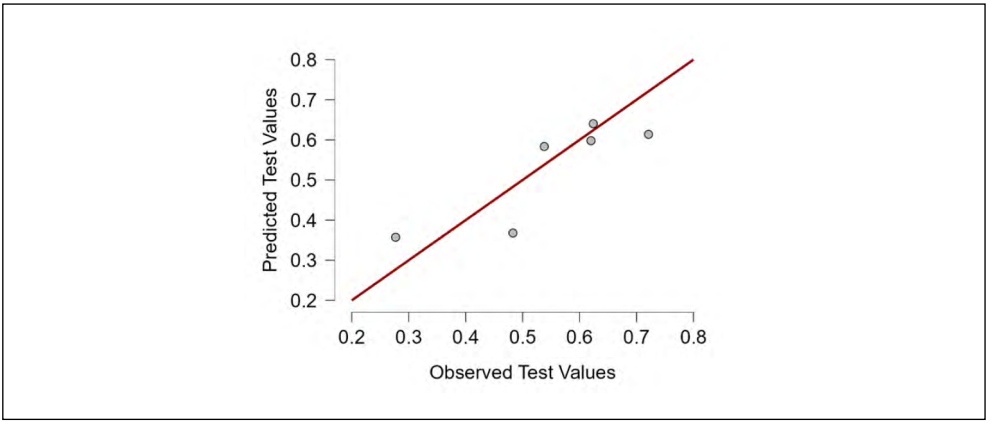

Fig. 3: **Predictive performance plot**

Source: own

are on the y-axis, while the observed values are plotted on the x-axis. The diagonal represents a perfect prediction. The points in the plot display the actual predictions made by the model. The distance of these points from the diagonal will determine the model's accuracy. The nearer the points are to the diagonal line, the more accurate the model is to be considered.

3.10 Additive explanations for predictions

Tab. 10 demonstrates additive explanations for the predictions of test set cases and how different features influence the collective outcomes of an overall prediction (Tab. 10). The different test cases are identified in the "Case" column, while in the "Predicted" column, the predicted values accompanying each case are revealed. The "Base" column indicates the baseline prediction for each case, showing what would happen if all other features were set to zero. Tab. 10 also provides the contribution of specific factors to the predictions, with the "Digital teaching competence" column reflecting how this particular feature impacts the overall prediction for each case. Then, a column will represent the moderating effect for prediction as part of "Moderating effect 1." Also, it will show the contribution that goes to teacher self-efficacy for the overall prediction of any given case. Thus, these columns offer a comprehensive view of all kinds of interacting features and what is coming about in terms of their respective contribution to the predictive model results.

Tab. 10: **Additive explanations for predictions of test set cases**

Case	Predicted	Base	Digital teaching competence	Moderating effect 1	Teacher self-efficacy
1	0.614	0.452	0.044	0.021	0.098
2	0.368	0.452	5.755×10^{-4}	0.033	−0.117
3	0.357	0.452	0.019	0.022	−0.135
4	0.64	0.452	0.048	0.023	0.118
5	0.583	0.452	0.024	0.064	0.044

Source: own

3.11 Mean squared error plot

Fig. 4 shows the mean squared error (MSE) plot, this plot visualizes the model's performance vs. "cost of violation of constraints." X-axis: cost of violation of constraints. It describes how the model can violate constraints imposed during the training process. The higher cost means there is more freedom for deviation. Y-axis: mean square error. It measures how much the difference between what the model predicted and the value is on average. The better the performance, the lower the mean squared error. Dashed line: training set mean squared error. This measures how well a model does on data that it already saw in training. Solid line: validation set mean squared error. This measures how well the model performs on entirely new, previously unseen data.

Performance trend: as the cost of violation of constraints increases (moving right along the X-axis), the mean squared error for both training and validation sets generally decreases. Allowing the model more freedom to violate constraints leads to better performance. Overfitting: the dashed line (training set) is always lower than the solid line (validation set), which means the model fits the training data too closely. This means the model has overlearned training data patterns, generalizing less accurately to unseen data. The plot describes a trade-off between the constraint violation and the model's performance. Higher flexibility could improve overall performance, but there is always the possibility of overfitting that reduces a model's ability to generalize well to new data. Balancing the violation of the constraint

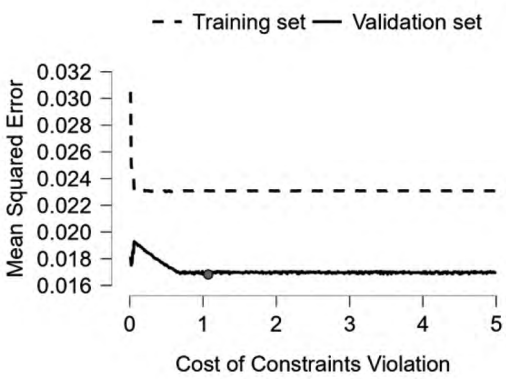

Fig. 4: **Mean squared error plot**

Source: own

with model complexity is an important aspect of building robust and reliable models.

4 Discussion

The findings of this research are highly insightful in grasping the intricate interplays among digital teaching ability, teacher self-efficacy, and staff career well-being. Since education is now on its way to going digital, it becomes of immense importance to know how these constructs interact and dance around one another in order to improve effective pedagogical techniques further and sustain academic settings. This discussion chapter outlines the implications of the accepted hypotheses, such as empirical results, to be compared with current literature and the theoretical frameworks. Through an analysis of the accepted hypotheses, we can further describe why enhancing the faculty member's level of digital teaching competencies affects self-efficacy and overall career happiness and wellness.

Confirmation of the first hypothesis – that digital competence has a strong impact on faculty career well-being should reinforce increasing consensus in education research that technology is key to securing positive faculty experiences. Findings indicate that teachers with high levels of digital competency are best placed to deal with challenges from new education practices, giving rise to even greater job satisfaction and higher work engagement. This is consistent with earlier research that has shown that it is through the proper incorporation of technology in instruction that teachers can have more sense of involvement and satisfaction (Kholifah et al., 2023; Ninković et al., 2024). Digital competencies promote the abilities of instructors towards more active learning, professional competence, and satisfaction. The findings highlight that effective support for institutional and professional development on digital matters can only be initiated if the need for training and resources in this respect is ongoing and related to the increasing digitization of the environment.

The second supported hypothesis also posits that digital instructional ability affects teacher self-efficacy significantly; therefore, with appropriate technology, teachers' self-confidence in teaching will increase. It shows that the teachers who think that they are proficient and capable of digital teaching are likely to think that they are excellent teachers; these two also create a positive correlation with general self-efficacy (Wong et al., 2023). Since this is a significant relationship, greater self-efficacy has been linked to enhanced motivation, more impressive persistence under adversity, and more effective instructional practices. When teachers have confidence in their abilities, they will attempt new, more effective instructional practices and will engage meaningfully with students in class, leading to an active learning environment for everyone. This study emphasizes the need for higher education institutions to incorporate digital competencies into the pedagogy design process of the faculty of a strategic academic approach. This implies that self-efficacy and job satisfaction in general become essential to individual teachers and the educational community.

The reception of hypothesis three shows that teacher self-efficacy deeply mediates the relationship between digital teaching competence and faculty career well-being. This finding emphasizes the role of self-efficacy as a significant psychological mechanism that makes digital teaching competencies consequential for well-being. The results yield the role of self-efficacy as a mediator because it promotes enhancing digital skills and beliefs in one's ability to use digital skills effectively (Uçar & Zarfsaz, 2023). Educators with a higher self-efficacy tend to approach their teaching roles with optimism, resilience, and a better end towards job satisfaction and more commitment to the profession. Therefore, this suggests a need for educational institutions to develop training that develops self-efficacy through mentoring, collaborative skills, and positive feedback, creating a supportive context for developing skills and psychological empowerment.

The fourth hypothesis acceptance ensures that pedagogical content knowledge strongly moderates digital teaching competence and teacher self-efficacy. This identifies the sophistication of knowledge fields, in which digital competence is more effective with the presence of robust pedagogical content knowledge. Teachers with extensive subject knowledge and sound teaching practices are capable of effectively incorporating digital technologies for improving teaching and well-being (Göbel et al., 2023). This highlights the need for professional development that involves both pedagogical and digital skills, facilitating more effective teaching by faculty. Institutions need to create collaborative learning environments where the faculty can exchange best practices to improve job satisfaction and professional development (Khan et al., 2022).

In all, the findings illustrate the interconnectedness of teacher self-efficacy, digital teaching competence, and faculty career well-being. The endorsement of all four hypotheses underscores the importance of enhancing digital competence and self-efficacy among teachers since these directly impact their job satisfaction and teaching experience. Identifying pedagogical content knowledge as a significant moderator, schools need to prepare faculty to deal with contemporary teaching issues. Future initiatives should aim to develop digital competence, self-efficacy, and pedagogical knowledge to promote teacher well-being and enhance student learning.

4.1 Implications of the research

Theoretically, this research makes a contribution to the literature by bridging Bandura's social cognitive theory and the technology acceptance

model to account for the interplay between digital teaching capability, self-efficacy, and the career well-being of faculty members. The results affirm the centrality of digital competency in influencing faculty lives and point to the moderating effect of pedagogical content knowledge. By showing these high-order interplays, this research builds on current frameworks and offers groundwork for future inquiries into faculty development within digital learning.

Practically speaking, the research highlights the imperative for institutions to advance faculty digital capabilities through selective professional development opportunities. Professional development efforts should not only address digital capabilities but also prioritize pedagogical approaches to maximizing technology in teaching. Additionally, creating an environment of collaborative learning where best practices are exchanged among faculty members can improve job satisfaction and instruction. Institutional policies must focus on ongoing support for faculty in the integration of digital tools to realize long-term gains for both students and educators.

4.2 Limitations and future research directions

This research has some limitations that must be noted. The study was carried out in Saudi Arabian colleges, which can restrict the external validity of the findings to other education systems with varying technological support and pedagogical approaches. The study was also cross-sectional in nature, which fails to reflect changes in faculty digital competency and well-being over time. Longitudinal studies might yield more insights into the changing effect of digital teaching competence on the career well-being of faculty members.

Future studies ought to investigate qualitative approaches to develop a better insight into faculty use of digital tools and their effect on teaching methodologies. Broadening the study across educational levels and disciplines would better establish the validity of the findings and increase their generalizability. Further, exploring other prospective moderators, like institutional support and technology accessibility, may offer a more detailed view of the drivers of faculty career well-being in digital education.

Conclusions

Finally, this study inquiry is compelling for interactive interactions among digital instructional ability, teaching staff career health, instructor self-confidence, and instructional content information. The inference of this research sustains the premises that augmenting teachers' teaching technology/digital abilities may powerfully help them feel effective and satisfied at work overall, indicating the integral part professional training may have to contribute in today's educational contexts. To wrap it up, after acknowledging the moderating and mediating effects of pedagogical content knowledge and self-efficacy, the study opines that technological and pedagogical expertise needs to be blended into faculty training. With the dynamic digital ecosystem changing every minute, responding to schools' changing needs is the key to which this research lays on its foundation for informing decision and policy implementation regarding an efficient strategy for teaching well-being and thus having implications for student outcomes.

This research adds to the literature on digital teaching competence, career well-being of faculty, and teacher self-efficacy as developed in the knowledge base that guides educators by shedding light on inter-relationships between these constructs. Since all the hypotheses were accepted, it emphasizes the integration of digital competencies into educational psychology and professional development framework. Findings indicate that digital teaching capability directly influences career well-being among faculty while it influences positively teachers' self-efficacy as a mediator to this connection. The findings, therefore, support the self-efficacy theory that might advocate for enhancing emotions of competence and satisfaction regarding jobs through improving digital capacity among academics. Notably, the pedagogical content knowledge moderating effect directs to the mastery by teachers of both content and technology in creating maximal professional results. This way, such concepts enhance a collection of theoretical models in educational research, particularly when discussing teacher development; this would encourage researchers to investigate further relationships between technology, pedagogy, and teachers' well-being.

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