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Analysis of the Heterogeneity of Apartments and Its Impact on Rental Prices in Prague Using Web Scraping and Hedonic Regression Model

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Abstract

The study analyzes the heterogeneity of the housing stock and its impact on rent levels in Prague. Using web scraping and hedonic log-log regression on data from the SReality portal (20 184 apartments offered), it quantifies the impact of layout, size, and amenities (elevator, terrace, garage, facilities, new construction) on the price per square meter and examines the spatial and temporal variability of these factors. It compares classic indices (Laspeyres, Paasche, Fisher) with their hedonic variants to assess whether changes in the structure of supply distort aggregate statistics. The results show significant spatial heterogeneity of parameters, but only slight differences between traditional and hedonic indices in short-term monitoring.

Keywords

Rent prices, hedonic regression, heterogeneity of housing stock, web scraping

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INTRODUCTION

The issue of housing affordability is currently one of the most debated topics in urban and regional policy, not only in the Czech Republic but also in the broader European context. It has significant macroeconomic, social, fiscal, demographic, and urban planning implications that directly affect the performance

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of the entire economy. Particularly in metropolitan areas such as the capital city of Prague, there has been a significant increase in housing costs, with the rental housing segment exhibiting specific dynamics that differ from the owner-occupied housing market. In this context, there is an increasingly urgent need for a more in-depth analysis of the factors that determine the development of rental prices, including their spatial, temporal, and structural variability.

Several entities publish rent price developments in the Czech Republic at varying intervals (and with varying degrees of reliability). Among private entities, one example is the Deloitte Rent Index (Deloitte, 2025), which lists rent prices in CZK/m² in regional capitals of the Czech Republic and their quarter-on-quarter developments. At the same time, the Czech Statistical Office publishes monthly data on apartment rents, which it estimates using data obtained through a sample survey of rental providers. This survey includes rental providers (e.g., real estate agencies, apartment managers, housing cooperatives) who submit monthly electronic reports by the 20th day of the following month. The results of the survey are used, among other things, to determine price developments in the «Housing, water, energy, fuel» category of the consumer price index. Contractual rent is a separate item within this category of the consumer price index, with each item, i.e., a specific rent, being represented by one reporting entity (CZSO, 2025).

Aggregated price indicators published by both the Czech Statistical Office and private entities are an important source of information on developments in the rental housing market. However, they share a common methodological feature – they ignore the fact that the housing stock is highly heterogeneous. Apartments differ not only in size and layout, but also in a number of attributes that can significantly affect the final rental price – for example, the presence of a balcony, elevator, parking options, or whether the building is new. These characteristics can have a significant impact on price, but in the official index they are usually aggregated to the level of the territory, which may be heterogeneous, and always represented by a single average value. The result is a considerable simplification, which reduces the usability of the index for market analysis, comparison of individual segments, or the creation of regional housing policy. This problem is all the more serious in a situation where rents across different locations are to be compared or their development over time monitored.

Given the limitations of official indices, alternative approaches based on more data-intensive methods have been increasingly discussed in recent years. Online real estate portals, which provide extensive data on rental and owner-occupied housing offers, are becoming an important source of information in this regard. Modern techniques for collecting data from the internet, in particular web scraping, make it possible to systematically collect and analyze this information in real time and with a high degree of granularity. This opens up opportunities for a deeper understanding of market mechanisms and the prediction of price trends. In recent years, a number of expert studies have been published demonstrating the use of scraped data in modeling real estate prices (e.g., Jach, 2021) and rent developments (Meyberg et al., 2024), which demonstrate the practical benefits of these methods in the context of a dynamically evolving housing market.

In addition to providing a large amount of data on rent bid prices in various areas, online real estate portals also allow users to obtain detailed information on the characteristics of the apartments themselves. Authors Mullen and Procházka (2025) and Solovev and Pröllochs (2021) use the so-called hedonic regression method to analyze characteristics and their impact on rental prices. This makes it possible not only to quantify the extent to which characteristics influence rental prices, but also to adjust rental prices for the influence of these characteristics. Malpezzi (2003) shows that ignoring variation in structural attributes produces biased comparisons across space and time, and that hedonic methods offer an alternative by decomposing market prices into characteristic values and enabling comparability across space and time. The Ministry of Finance of the Czech Republic, for example, began using the hedonic regression method in combination with web scraping in 2025 to publish rent bid prices at the cadastral area level (MFCR, 2025).

The article aims to verify how the extent of heterogeneity of apartments affects the resulting rent level. Particular attention is paid to the question of whether this heterogeneity can cause systematic distortions in the construction of aggregate indicators, in particular regional rent statistics and price indices in individual periods. As part of the analysis, we also focus on identifying the key factors that influence rent levels in Prague – specifically, we examine how rent varies depending on the size, layout, and amenities of the apartment. The aim is also to assess the extent to which the hedonic pricing model can explain price differences between different types of apartments and whether this method is a suitable tool for constructing price indicators that better reflect the actual market situation.

The analytical part is divided into two main sections. In the first section, we use a hedonic regression model to quantify the price impacts of individual attributes across cadastral areas. We monitor how the influence of specific characteristics – such as the existence of an elevator, terrace, garage parking space, or apartment equipment (furniture and other equipment, e.g., washing machine) – differs in various spatial contexts. In the second part, we focus on the time dimension of heterogeneity: we analyze whether the composition of the housing stock changes over time and whether these changes affect the development of commonly published price indices. To this end, we use a comparison of classical indices (Laspeyres, Paasche, and Fisher) with their hedonic variants. The key tool in this part is the hedonic imputation method – see Eurostat (2013), which allows price indices to be constructed by fixing a set of attributes, thereby eliminating the influence of changes in the structure of the housing stock on the observed price developments.

The results of this study can contribute to a deeper understanding of the functioning of the rental housing market in Prague and can also serve as a basis for more targeted and effective interventions both at the level of public administration and on the part of private actors operating in the real estate market. Last but not least, given Prague's position in the national context, they can also contribute to a deeper understanding of the connections with the economic development of Czechia as a whole.

The R computing software (R Core Team, 2024) was used for data processing, web scraping model construction, and calculations. Spatial dependency analyses were performed using the *sf* (Pebesma, 2024) and *RCzechia* (Jedlička et al., 2024) packages, and the results were visualized using the *ggplot2* package (Wickham, 2024).

1 LITERATURE REVIEW

1.1 Rental housing in Prague

Rental prices in the Czech Republic cannot be considered a homogeneous phenomenon – on the contrary, they are characterized by a high degree of heterogeneity, which is evident not only between individual city districts, but also between different types of apartments. Rental differences are influenced by a number of factors, including the size and layout of the apartment, its technical condition and level of amenities, as well as the broader urban and socioeconomic context of the specific location. This differentiation reflects the complex interaction between supply and demand in the market, institutional conditions, demographic characteristics of the population, and the investment motivations of property owners.

In the context of Prague, the analysis of rental housing price heterogeneity is particularly urgent and relevant at present. In recent years, housing in Prague has faced significant rent increases. However, rent price developments are highly disproportionate across Prague's districts. Hromada (2021) shows that the strongest fluctuations in rental prices caused by the COVID-19 pandemic primarily affected the center of Prague, while the periphery was less or only slightly affected. This may also be due to the growing pressure of short-term rentals, which are more prevalent in the center of Prague. A study by the Prague Institute of Planning and Development (see IPR Prague, 2024) shows that the use

of short-term accommodation through the Airbnb platform in Prague declined significantly during the COVID crisis, but is now on the rise again. Short-term rentals in city centers can reduce the supply of long-term housing and further increase the price gap between individual segments.

The topic of short-term rentals is closely linked to so-called investment apartments, where households buy apartments precisely because of the rapid growth in prices, not only in recent years in Prague. The fact that real estate currently serves primarily as an investment product is evidenced by a study by Andrlé and Plašil (2019), which defines the concept of real estate price overvaluation as the ratio of the average price of real estate to the average price at which the average household can afford to purchase real estate. The study then constructs a time series of real estate price overvaluation, which shows that overvaluation in Czechia is increasing, thereby reducing the affordability of real estate for average Czech households. At the same time, however, the number of mortgages granted in Czechia is not falling significantly (CBA, 2025), from which it can be concluded that real estate purchases for investment purposes are gradually becoming more prevalent in the real estate market.

From the above, it can be concluded that a significant part of the population, not only in Prague, may increasingly seek rental housing as an alternative to unaffordable owner-occupied housing in the future. Increased demand for rental housing may then lead to further growth in rental prices. This certainly does not contribute to the stability and predictability of the housing situation. It is therefore desirable to have a strong database with sufficient granularity to describe the current situation and, if necessary, as a basis for forecasting future developments. At the same time, it is desirable to have a good knowledge of the real estate fund, including the impact of various housing characteristics on rental prices and their distribution at time and space.

1.2 Web scraping

With the development of digital platforms, online portals now offer a wealth of information about trends in society. In recent years, there has been a growing interest in the use of web scraping in economic and statistical analyses, especially when it comes to spatial data. However, Brenning and Henn (2023) also point to legal and ethical issues and data quality problems as the main challenges associated with this method.

For traditional data collection methods used by the state statistical service, such as questionnaire surveys or administrative registers, it is common practice to obtain informed consent from the persons whose data is being collected. In the case of web scraping, this consent is usually lacking because the information is obtained automatically from publicly accessible websites. It is therefore desirable to collect and publish data in an aggregated form so that it does not contain any sensitive information.

In contrast, questionnaire surveys and registries have limited ability to capture current market dynamics, especially when it comes to short-term price fluctuations and spatial heterogeneity of supply. Studies focused on predicting rents and real estate prices, such as Meyberg et al. (2024) or Jach (2021), show that web scraping allows for faster and more detailed processing of price levels than official statistics, while enabling spatial analysis at the level of small geographical units. Meyberg et al. (2024) also note that real estate portals are primarily intended for the general public. Since this information is publicly shared for the purpose of selling and renting real estate, its collection can be considered ethically justifiable.

1.3 Hedonic prices

The issue of internal heterogeneity in the urban housing market was systematically analyzed by Goodman (1978), who showed in his classic study that real estate prices vary significantly not only between regions but also within metropolitan areas themselves. Using data from the city of New Haven in the US, he demonstrated that the price effects of housing attributes and price developments over time vary

significantly between individual submarkets, defined by a combination of location and period. This finding led to the recommendation to segment the market and construct hedonic models separately for individual parts of the city. In line with these conclusions, it can also be argued in the context of Prague that a suitable strategy for capturing the spatial variability of rental prices is to apply hedonic regression at the level of sub-territorial units, such as cadastral areas.

Hedonic regression is used to quantify how individual characteristics of a product or good affect its market price. It is based on the assumption that the price of a complex good (e.g., an apartment, car, or job) is given by the sum of the implicit prices of its partial attributes – the so-called hedonic prices. These prices cannot be observed directly, but they can be estimated statistically based on the variability in observed prices and corresponding characteristics. Hedonic regression is therefore typically applied in situations where goods are not homogeneous but consist of different combinations of characteristics whose value needs to be expressed separately.

The principle of hedonic pricing is to derive the marginal utility value of individual attributes from consumer market behavior. For example, if apartments with balconies consistently fetch higher prices than comparable apartments without balconies, the difference in price can be interpreted as the implicit price of this attribute. This approach can be used not only in the real estate market, but also in the valuation of environmental goods (e.g., air quality) or working conditions (e.g., job risk). The hedonic method is thus a tool for revealing, from market data, the value of unobservable or difficult-to-value characteristics (Vorel et al., 2023).

There are several methods for estimating hedonic prices – the most common are classical linear regression, quadratic, or log-linear models. The choice of an appropriate functional form depends on the nature of the data and expectations regarding the relationship between attributes and price. Some approaches (such as quantile regression) also allow for different attribute values across price distributions, i.e., certain characteristics may be valued differently in cheap and expensive market segments. This is demonstrated, for example, by Liao and Wang (2012), who combine quantile regression with spatial modeling and conclude that the implicit prices of attributes vary significantly across quantiles of the price distribution.

Mayer et al. (2019) examine the accuracy and volatility of various methods for estimating and updating hedonic pricing models. The authors compare methods such as classical linear regression, robust regression, and machine learning methods and conclude that robust regression models are sufficiently stable and accurate.

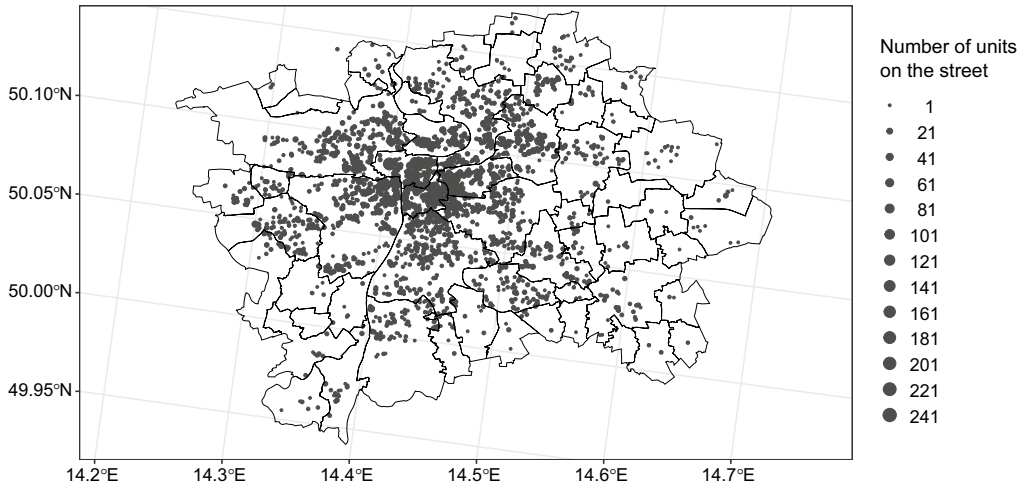
This paper will use a log-log linear model, as it offers a compromise between robustness and interpretability. The transformation to logarithmic form ensures that the assumptions are met, as the distribution of rents, like the distribution of wages, has heavy tails. Compared to advanced machine learning methods, the log-log model has the added advantage of being less computationally intensive, requiring no complex parameter tuning, and preserving the transparency of the relationship between variables, which is important for analytical and political-economic purposes.

2 DATA AND METHODS USED

2.1 Data

For the purposes of this analysis, we used data on rental prices in Prague's city districts. The data was obtained using web scraping from the SReality real estate portal, which has a significant share of the real estate market in Czechia. Data scraping from the website took place gradually on November 24, 2024, December 20, 2024, January 18, 2025, February 19, 2025, March 16, 2025, April 21, 2025, and May 23, 2025. In this way, information was obtained on a total of 20,184 apartments in Prague. Figure 1 shows the spatial distribution of the data.

Figure 1 Spatial distribution of collected housing units



Source: SReality, own calculations

The data is deliberately limited to the capital city of Prague, as we believe that Prague is currently undergoing an intense transformation characterized by high growth in housing prices with different developments between the center and the periphery. It is precisely the large spatial and socio-economic differences between the city’s districts that seem suitable for detailed hedonic analysis.

The following information about the offered apartments was obtained using web scraping:

- the cadastral area and street where the apartment is located,
- the price and floor area of the property (the price per square meter is derived from these variables for calculation purposes),
- layout of the property,
- and further information on whether the property is furnished, whether there is an elevator in the building and whether barrier-free access is available, whether the property has a balcony or terrace, and whether a cellar, garage, or parking space is available with the property. For calculation purposes, this information is converted into binary variables, where 1 means that the property meets a specific attribute and 0 means otherwise.

2.2 Methods used

Our goal is to decompose rental prices using a hedonic regression model (Vorel et al., 2023) defined as:

$$\log Y = \beta_0 + \sum_{j=1}^3 \beta_j D_j + \gamma_0 \log \frac{X}{M} + \sum_{k=1}^K \delta_k Z_k, \tag{1}$$

where:

- Y – rent price in CZK/m²,
- β_0 – constant corresponding to the rent price of an apartment of standard size and layout 2+1 (layout 2+1 is considered the most common in the analysis and is therefore chosen as a reference),⁴

⁴ The designation "x+1" in the apartment layout indicates the number of living rooms (x), with "+1" denoting the kitchen. For example, a 2+1 apartment includes two rooms (e.g., a bedroom and a living room) and a separate kitchen.

D_j – binary variables indicating a residential unit with a layout other than 2+1, the model distinguishes between layouts “1+1”, “3+1” and “4 or more rooms”;

X – floor area of the apartment in m^2 ,

M – median floor area in the given area and layout in m^2 ,

Z_k – binary variables indicating the presence of individual attributes, which are:

- elevator,
- equipped – indicating whether the apartment is fully furnished or not,
- garage,
- kitchenette – indicating whether the apartment has a kitchenette or whether the kitchen is in a separate room (A kitchenette is part of the living area, usually the living room. In this case, the apartment does not have a kitchen separated from the other rooms.),
- new building indicating whether the apartment is located in a new building in very good structural condition.

The variable X/M ensures that after logarithmization, the expression has a zero value if $X = M$, i.e., if the floor area corresponds to the median in a given location and layout. This allows β_0 to be interpreted as the price of a standard 2+1 apartment of a typical size without other price-determining attributes. The variables D_j take the value 1 if the apartment corresponds to the given layout, and 0 otherwise. Similarly, the variables Z_k take the value 1 if the apartment has the given attribute, and 0 otherwise. The coefficient γ_0 for the variable $\log(X/M)$ can be interpreted as elasticity – i.e., the percentage change in rent Y if the ratio of the floor area of the apartment X to the median area M in a given location and layout increases by 1%.

The model described above is used to divide rental prices into the average base price of a typical apartment adjusted for additional parameters. At the same time, we are able to estimate the prices of individual parameters from the model. By estimating the coefficients of the equation separately in individual areas, we can observe how both the price level and the prices of individual parameters differ across time and areas. It is therefore clear that the hedonic regression model described above is key to examining both spatial and time heterogeneity.

As part of the analysis of spatial heterogeneity, we first examine the spatial dependence of rental prices using the Moran's test of spatial autocorrelation (Bivand et al., 2008). This indicator allows us to verify whether geographically close areas tend to show similar values of the phenomenon under study – in our case, rental prices. We also use its local extension, the so-called LISA statistics (Anselin, 1995), which allow us to break global information into individual units and identify specific areas forming clusters with high or low values, or outlying units with atypical behavior.

When estimating the coefficients of the hedonic model in each territory separately, we may encounter a problem related to the low number of observations, as there may be territories where the rental housing market is not yet sufficiently developed. In order to have a sufficient number of degrees of freedom for the regression model in each cadastral area, we assign data on rental prices from neighboring cadastral areas to each area with an insufficient number of observations. Based on the output of Moran's test of spatial autocorrelation described above, we can assume that rental prices from neighboring areas do not differ significantly from rental prices in the monitored area with an insufficient number of observations. LISA statistics also allow us to identify outlying areas, so we assign observations from neighboring areas to each area only if, according to LISA statistics, there is no significant difference in rent prices in that area.

When estimating the coefficients of the hedonic model, the observations assigned to a given area from neighboring areas will be given a reduced weight, so that observations from the given area have the greatest influence on the calculation. A weighted regression model will therefore be used to calculate the coefficients in areas with fewer observations. The weights of individual observations for the calculation

of the hedonic model in a given area will then be selected using the so-called Moran's distance (Bivand et al., 2008) w defined as:

$$w_i = \frac{1}{d_i^p}, \tag{2}$$

where d is the distance of the apartment from the center of the given cadastral area, and p is an optional parameter; the higher it is, the more the weight of more distant observations decreases. For $p = 1$, distant observations have relatively high weight, which threatens to completely erase local extremes. For higher p values, more distant observations can have such low weight that they have almost no effect on the calculation itself. Therefore, we will choose $p = 2$ as a compromise for the calculation.

The output of the spatial dependency analysis will be a comparison not only of rental prices, but also of the prices of individual attributes in individual cadastral areas.

We base our analysis of time heterogeneity on a comparison of classic price indices (Laspeyres, Paasche, Fisher) with their hedonic counterparts. Hedonic indices can be constructed using the so-called hedonic imputation method, as defined by Eurostat (2013), based on the above-mentioned hedonic regression model. According to the hedonic imputation method, we estimate the price of rent in territory u and time t using the equation of the hedonic regression function as:

$$p_t^u = \exp(\beta'_0 + \sum_{j=1}^3 \beta'_j D_j^0 + \gamma'_0 \log \frac{X}{M} + \sum_{k=1}^K \delta'_k z_k^0). \tag{3}$$

The hedonic equivalent of the Laspeyres price index $I_{h,t}^L$ then corresponds to:

$$I_{h,t}^L = \frac{\sum_u q_0^u \widehat{P}_t^u}{\sum_u q_0^u P_0^u}, \tag{4}$$

where \widehat{P}_0^u corresponds to the rental price estimated according to Formula (3) in the territory u and at time $t = 0$ and q_0^u corresponds to volume shares in territory u and time $t = 0$. This is therefore the share of the rental market in the territory u on the total rental market under review.

The calculation therefore involves estimating the model coefficients in the individual areas under review. Based on the estimated models, the rent price is predicted in each period t using data from the base period 0. Formula (3) thus expresses the base rent price and attribute prices in prices from period t . However, the distribution of attributes always corresponds to the distribution from period 0. This allows the prices of comparable units to be compared across all periods.

Paasche's hedonic price index $I_{h,t}^P$ can then be generalized similarly as:

$$I_{h,t}^P = \frac{\sum_u q_t^u \widehat{P}_t^u}{\sum_u q_t^u P_0^u}. \tag{5}$$

As in the case of classic aggregate indices, Fisher's index is then obtained as the geometric mean of the two described above.

By comparing classic price indices with hedonic indices, we can verify whether classic indices are distorted due to the changing distribution of apartments offered on real estate portals.

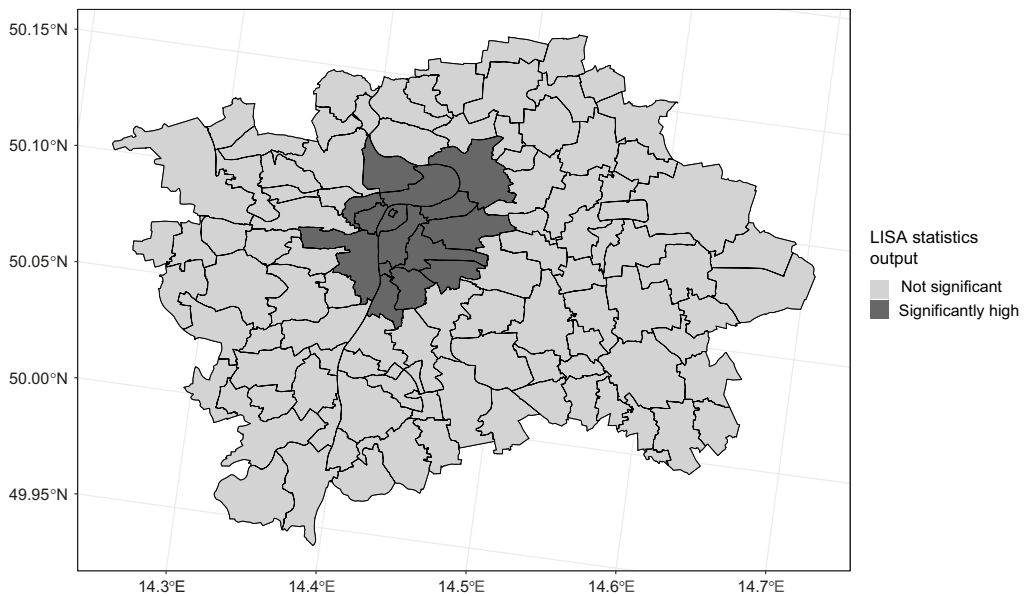
3 RESULTS AND COMMENTS

The aim of our analysis is to identify factors of spatial and time heterogeneity of apartments in terms of their impact on rent levels. In the first part of the chapter, we analyze the distribution of rents and possible differences in the distribution of various attributes affecting rents across the cadastral areas of Prague. In the following section, we analyze whether the distribution of price-determining attributes of apartments offered for rent changes over time.

3.1 Analysis of spatial heterogeneity

The first step in the analysis is to determine the extent to which rental prices vary across different areas. Using LISA statistics, we identified areas that may differ from others in terms of their rental price levels, and we will therefore treat these areas separately in the subsequent analysis. The outputs of the LISA statistics at the level of Prague's cadastral areas are shown in Figure 2.

Figure 2 Evaluation of LISA statistics in Prague cadastral areas



Source: SReality, own calculations

Figure 2 shows that the darkly shaded area, roughly corresponding to the city centre, has significantly higher rents than the rest of Prague. In our analysis, we will therefore distinguish between the darkly shaded areas and the rest of the city, which is lightly shaded (further referred to as the City centre and the Peripheral areas).

This is followed by a decomposition of rental prices in individual cadastral areas using a hedonic regression model defined by Formula (1). Using this model, we decomposed the rental price Y into two components: the base price of a standard apartment (i.e., an apartment of median size without price-determining attributes) with a 2+1 layout represented by the parameter β_0 and contributions of individual attributes, which are expressed by coefficients δ_k . This approach allows us to compare rental prices between different locations, as we adjust the original prices to account for specific attributes. This means we always compare apartments with the same characteristics – i.e., the same size and no differences in equipment or location.

The model also allows the basic rent level to be determined for apartments with a layout other than the reference 2+1 layout, using coefficients β_j , which express the difference in the logarithm of the unit rent price (in CZK/m²) between the given alternative layout and the 2+1 layout. These coefficients thus quantify the relative deviation in rent prices for apartments with different layouts under otherwise identical conditions. To determine the logarithm of the rental price of an apartment with a layout other than 2+1, the relevant coefficient β_j is added to the estimated value of the parameter β_0 . Subsequent back-exponentiation can be used to obtain an estimate of the absolute level of rent in CZK/m² for a specific layout.

Table 1 shows rental prices calculated from parameters β_0 and β_j separately for the two areas defined in Figure 2. After de-logarithmization, the price parameters are converted to CZK/m².

Table 1 Estimated coefficient values

Territory	Apartment size			
	1+1	2+1	3+1	4 and more rooms
City centre	461 CZK/m ²	409 CZK/m ²	361 CZK/m ²	312 CZK/m ²
Peripheral areas	420 CZK/m ²	341 CZK/m ²	329 CZK/m ²	333 CZK/m ²

Source: SReality, own calculations

Table 1 shows that rents in the centre of Prague are generally significantly higher than in the peripheral areas, and by how much. We can also see that 1+1 apartments are the most expensive when converted to CZK/m², and that rental prices per m² decrease with each additional room. This may be due, for example, to the fact that the costs of construction and maintenance per m² decrease relatively quickly as the floor area increases.

Table 2 shows the values of individual attributes calculated from the estimated parameters δ_k from Formula (1). If a coefficient is statistically insignificant in a given area, and therefore the attribute does not significantly affect the rental price, the attribute value is listed in the table as 0 CZK/m². The parameters *Elevator* to *New building* correspond to the value in Kč/m² and indicate how much the rent for an apartment will increase if the apartment acquires any of the parameters.

Table 2 Estimated coefficient values

Territory	Attributes					
	Elevator	Equipped	Garage	Terrace	Kitchenette	New building
City centre	25 CZK/m ²	77 CZK/m ²	0 CZK/m ²	3 CZK/m ²	24 CZK/m ²	4 CZK/m ²
Peripheral areas	18 CZK/m ²	34 CZK/m ²	22 CZK/m ²	20 CZK/m ²	59 CZK/m ²	0 CZK/m ²

Source: SReality, own calculations

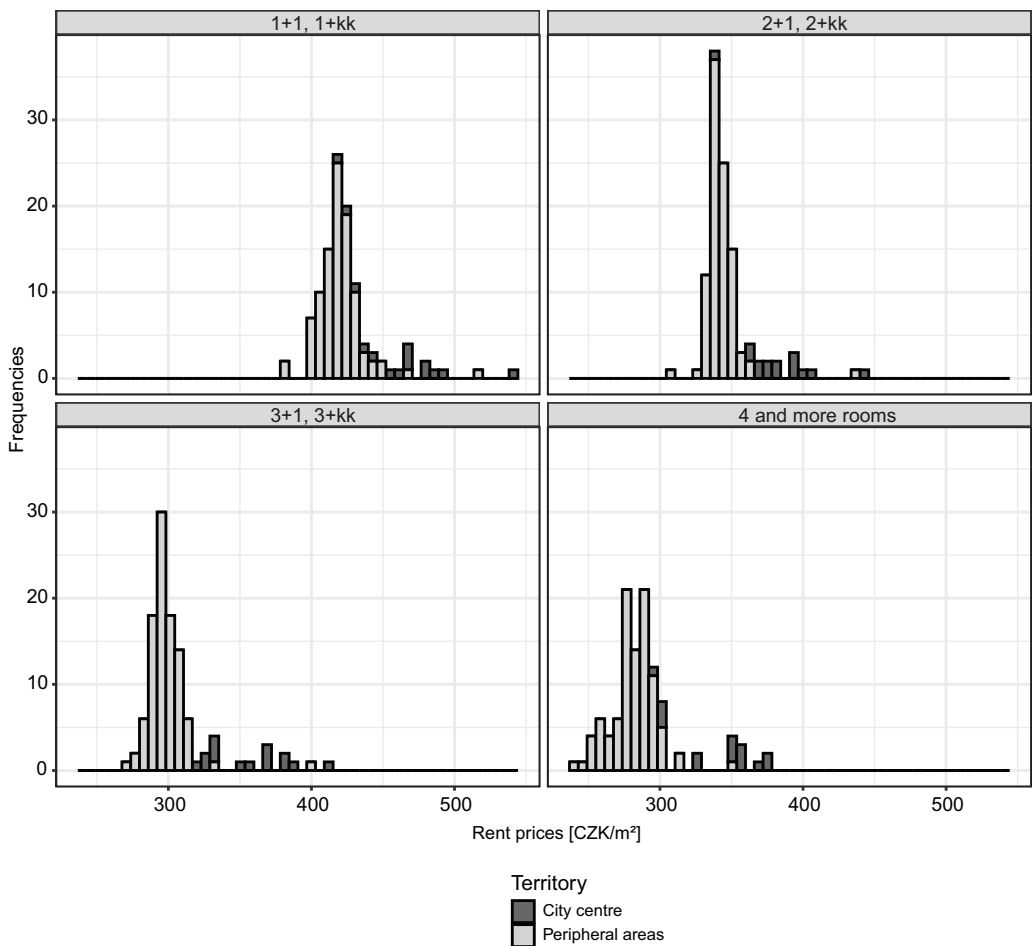
There are several reasons for the difference in prices of individual attributes between the centre and the peripheral areas of Prague. For example, due to the high proportion of historic buildings and generally very limited space in the center of Prague, it is unlikely that apartments with garage parking spaces will be offered. If the model does not have enough observations with garage parking, it will logically evaluate the garage parking coefficient as statistically insignificant. Conversely, in the case of the peripheral areas of Prague, we can assume a smaller proportion of historic buildings and a large proportion of tall urban buildings, where elevators are standard. Therefore, apartments with elevators may be relatively cheaper than apartments without elevators compared to the center, where an apartment in a building with an elevator is a greater luxury.

The above data shows that housing stocks in the centre of Prague and on the peripheral areas differ greatly in terms of both average rent and the distribution of individual attributes affecting the final price.

We then verified the heterogeneity of the housing stock in Prague across individual cadastral areas. We estimated the parameters of the regression model described above for each cadastral area of Prague separately. As described above, for cadastral areas with low numbers of observations (less than 200), we performed data imputation from surrounding areas.

Figures 3a and 3b below show the distribution of rental prices adjusted for the influence of attribute prices and the distribution of prices for individual attributes in individual cadastral areas estimated using the procedure described above.

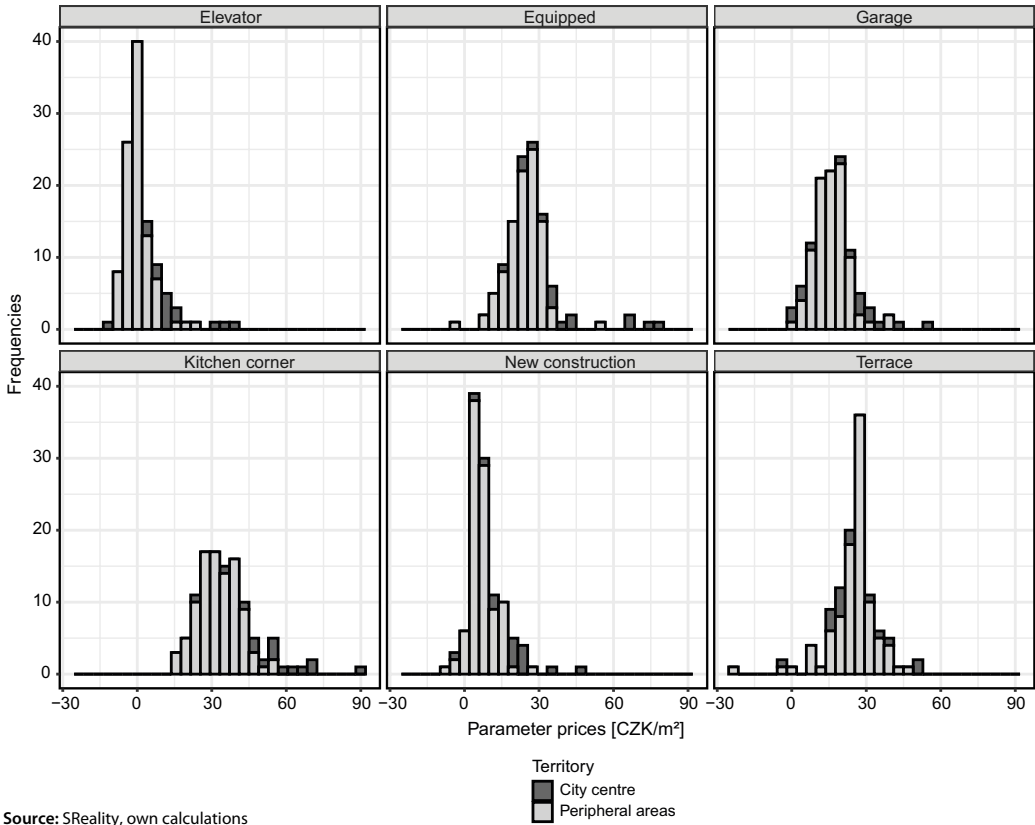
Figure 3a Average rental prices for apartments of various layouts according to the output of the hedonic regression model in cadastral areas in Prague



Source: SReality, own calculations

Both figures show that rents and individual parameters may vary by tens of crowns per square meter. It is therefore clear that the housing stock in Prague and rents are very heterogeneous across cadastral areas.

Figure 3b Average prices of apartment attributes according to the output of the hedonic regression model in cadastral areas in Prague



Source: SReality, own calculations

3.2 Analysis of time heterogeneity

Another aspect of heterogeneity is development over time. We will therefore examine whether there are significant differences in the distribution of residential units offered for rent across different periods.

The indices are divided into two spatial groups, the center and the periphery, as was the case in the spatial analysis above. The weights of these groups were determined according to volume shares in each period, and the price index was determined on the basis of these shares (for the Laspeyres index, shares in the base period are used, while for the Paasche index, shares in the given period *t* are used). Table 3 shows the volume shares in each period. The volume shares correspond to the share of observations in a given area and period in the total number of observations.

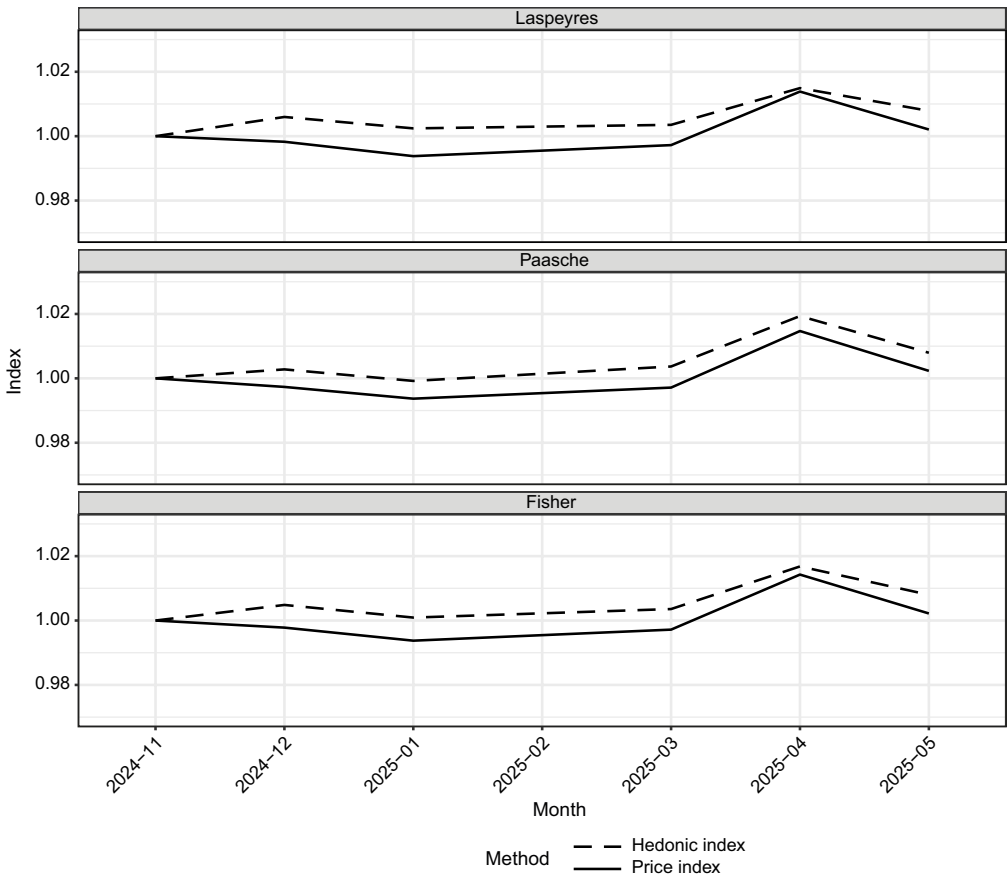
Table 3 Volume shares of observations in territories

Territory	Year-month						
	2024-11	2024-12	2025-01	2025-02	2025-03	2025-04	2025-05
City centre	0.59	0.64	0.62	0.61	0.58	0.62	0.63
Peripheral areas	0.41	0.36	0.38	0.39	0.42	0.38	0.37

Source: SReality, own calculations

Figure 4 shows a comparison of price and hedonic index developments over time. The comparison shows that traditional price indices and hedonic indices describe essentially identical developments. The average difference between traditional price indices and hedonic indices is approximately 0.25 percentage points. The results therefore suggest that the distribution of parameters for rental housing in Prague does not vary significantly across periods, and that the standard price indices can adequately describe rent price trends.

Figure 4 Comparison of the development of classic and hedonic price indices for rents in Prague



Source: SReality, own calculations

Given the greater complexity of calculating hedonic indices and compiling functional web scraping models, it can therefore be concluded that the data collection and calculation methods used to date are sufficient for a reliable description of (short-term) developments in rental prices over time. However, hedonic price indices are indispensable if we want more detailed information on the spatial heterogeneity of rents.

CONCLUSION

The article focused on analyzing the spatial and time heterogeneity of the rental housing market in Prague and assessing possible distortions that may arise when using aggregate price indicators without taking into account differences in apartment characteristics.

The theoretical part first described the current situation of the housing stock in Prague. Subsequently, existing approaches to measuring rent development in Czechia were presented, including official indices published by the Czech Statistical Office and private entities. The limitations of these indicators were then discussed, particularly in relation to the variability of the housing stock. In this context, the hedonic regression method was presented as a suitable tool for breaking down rent prices into the effects of individual attributes.

In the analytical part, hedonic regression was used for two main research objectives. First, a spatial analysis was performed based on modeling the influence of individual attributes (e.g., elevator, terrace, garage, apartment layout) in different cadastral areas of the capital city. The aim was to identify differences in the price impacts of these attributes between the center and the periphery of Prague. In the second phase, a time analysis was performed in which classic price indices were compared with their hedonic counterparts. Using the hedonic imputation method, we monitored whether the structure of the housing stock changes over time to such an extent that it could distort the development of the average rent price.

The analysis clearly confirmed that the rental housing market in Prague is significantly heterogeneous in terms of both space and structure. This is evidenced by the fact that the city center generally has higher rents, with differences compared to peripheral areas amounting to several tens of crowns per square meter. There is also a significant price difference between individual apartment layouts – the highest rents per square meter are for smaller apartments (especially 1+1), while the price per unit decreases with increasing floor space and number of rooms. This phenomenon can be interpreted as a consequence of declining marginal costs for the construction and maintenance of larger apartments and varying demand for different types of housing.

The analysis also revealed that price premiums for specific attributes (e.g., elevator, terrace, garage, furnishings) varied significantly between central and peripheral parts of Prague. This spatial differentiation is probably the result of differences in the supply and availability of these features – for example, elevators are standard in newer peripheral developments, while in the historic city center they represent a rare and therefore valuable feature. On the other hand, garage parking is often unavailable in the center, and therefore its impact on rent prices cannot be reliably assessed statistically. These differences point to the varying structure of the housing stock and consumer preferences between different areas of the city. Overall, it has been confirmed that the housing stock in Prague is not homogeneous and that its structure has a direct impact on the final rent price.

In terms of data stability over time, it cannot be said that, during the period in which the heterogeneity of the housing stock was examined, there was a significant difference between commonly used price indices and their hedonic variants. The average deviations between standard and hedonic indices in individual periods amount to only a few tenths of a percentage point, which shows that the structure of the housing stock offered for rent does not change significantly over time. Hedonic imputation thus did not confirm any significant distortion of traditional indices in terms of capturing the dynamics of the rental market over time. It follows that, in the case of short-term monitoring of price developments, current approaches remain methodologically adequate.

Overall, it can be concluded that while spatial heterogeneity require more sophisticated models and a locally specific approach, the time stability of the housing stock structure allows traditional indices to continue to be used to describe market dynamics. However, it should be emphasized that the web scraping model used in this study does not allow for a more detailed analysis of the heterogeneity of the housing stock over time, either due to the short period under review or due to the fact that data was only collected on one day per month. Nevertheless, the results of this study contribute to a deeper understanding of the functioning of the rental market in Prague and, at the same time, show in which cases it is appropriate to use more advanced statistical tools to achieve more accurate and interpretatively valuable outputs.

For a more detailed analysis, it would be appropriate to expand the hedonic model with additional variables, such as the building's energy performance indicator or information about the floor on which the residential unit is located. In particular, the energy performance of a building appears to be a potentially significant factor that may significantly affect rent levels in the future. Geopolitical events in recent years are likely to lead to increased energy efficiency, with the heating of residential units being an integral part of this. Including this variable in the model could thus make it possible not only to monitor whether current developments are actually leading to a greater proportion of energy-efficient buildings on the rental market, but also to reveal the extent to which energy efficiency is reflected in rent prices.

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Stakeholder Focus in Sustainability Management – Statistical Analysis of the Hungarian Micro-Enterprises

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Abstract

The pursuit of sustainable development has emerged as a pivotal concern in contemporary business discourse. Sustainable development is increasingly important for businesses, including micro-enterprises, which must address sustainability challenges to stay competitive and viable. A key aspect of corporate sustainability is understanding stakeholder dynamics and translating their needs into business practices. Our research, using a questionnaire, examined the relationship between sustainability pressures from six key stakeholders on Hungarian micro-enterprises. We also explored whether distinct groups of variables could be identified based on the perceived directions of these sustainability pressures. Our findings, grounded on optimal scaling and multidimensional scaling analyses, reveal a clear link between how micro-enterprises monitor stakeholder activities and the focal points of these stakeholders' impact concerning sustainability. Managers must prioritize stakeholders based on their influence, whether through legal regulations, social values, or financial factors. This prioritization helps micro-enterprises effectively target their sustainability efforts, enhancing performance and long-term success.

Keywords

Sustainability, stakeholders, optimal scaling, micro enterprises, sustainable business

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INTRODUCTION

Nowadays, sustainability has become a central theme in both economic and social discourse, posing challenges not only for large corporations but also for micro, small, and medium-sized enterprises (SMEs) (Dembicka-Niemiec et al., 2023). In Hungary, SMEs are the backbone of the economy, playing a pivotal role in job creation and significantly contributing to national economic metrics and goals, such as GDP growth (Nouar and Popovics, 2022). Consequently, the imperative for sustainability is increasingly pressing for these businesses. This pressure is reflected not only in their efforts to remain competitive in the market but also in their compliance with environmental regulations, adherence to social responsibility standards, and support for sustainable development objectives.

For Hungarian SMEs, the commitment to sustainability goes beyond ethical or environmental considerations; it is crucial for maintaining long-term competitiveness. In the global marketplace, sustainable business practices are becoming increasingly important, driven by expectations from both consumers and business partners (Bajkó et al., 2022). Furthermore, both EU and domestic regulations are becoming more stringent, mandating companies to integrate sustainability into their core operations. Those companies that successfully embed these sustainability principles into their everyday practices not only contribute positively to the environment and society but also secure their own growth and long-term stability.

The role of micro-enterprises within the SME sector is particularly vital to the development of national economies and the advancement of sustainability principles, as these micro-entities form the foundation of the economic ecosystem. Although their individual contributions may appear modest, collectively they play a crucial role in job creation, the revitalization of local economies, and the promotion of innovation (Varga and Csiszárík-Kocsir, 2024). Micro-enterprises often utilize local resources and maintain strong ties with their communities, thereby facilitating the integration of sustainability practices at the local level. When these businesses successfully implement sustainable operational practices, they can serve as an example for other economic actors, creating a ripple effect that influences the broader economic and social environment.

In our research, we investigate the perspectives of Hungarian micro-enterprise CEOs, specifically focusing on the sources of sustainability pressure they experience – essentially, which stakeholders are influencing them to initiate sustainability efforts and whether correlation could be determined between the pressure directions. Our questionnaire-based survey concentrates on stakeholders commonly identified in the literature, including government and regulatory bodies, customers and consumers, competitors, society, employees, banks and investors.

The structure of our study is organized as follows. The next chapter provides an overview of the significance of various corporate stakeholders, particularly in relation to sustainability initiatives. Section 2 outlines the research methodology, detailing the main characteristics of the data collection process, the database, and the specific research questions addressed. Section 3 presents the findings related to our research questions, while the final chapter summarizes the study's results and discusses its limitations.

1 LITERATURE REVIEW

To effectively implement corporate sustainability initiatives, several key management aspects must be prioritized. Foremost, company leadership must demonstrate a firm commitment to sustainability and integrate this commitment into the company's overall strategy (Nagy et al., 2021; Surman and Böcskei, 2023a). As highlighted by Nagyné Halász et al. (2023), sustainability challenges can disrupt and reshape managerial decision-making processes. When managers perceive sustainability initiatives as business opportunities, they are more capable of balancing these efforts, thereby minimizing the risk of compromising economic performance (Das and Rangarajan, 2020).

Beyond commitment, it is crucial for companies to establish clear, measurable sustainability goals aligned with both national and international regulations, as well as broader sustainable development objectives. Defining sustainability targets specific to the company's context (Kantabutra, 2024) and aligning them with the expectations of all stakeholders is essential. These objectives should be seamlessly integrated into all aspects of corporate operations, including production, procurement, logistics, and marketing. In managing sustainability within an organization, companies must carefully consider which stakeholder needs to prioritize, accurately understand these needs, and determine how they can be effectively translated into actionable strategies.

Implementing sustainability practices within corporate settings presents a complex challenge, however, much of the existing research predominantly focuses on large corporations and their sustainability initiatives (Delgado-Ceballos et al., 2023). Das and Rangarajan (2020) provide a comprehensive analysis, demonstrating that sustainability practices positively impact organizational excellence in large firms, as evidenced by sustainability reports. Numerous studies have highlighted the correlation between sustainability actions and financial performance of large companies (e.g., Mirgen and Tepeli, 2024), whereas research addressing SMEs remains limited (e.g., Surman and Böcskei, 2023b). Therefore, focusing solely on large corporations may result in overlooking the significant role which SMEs play in promoting sustainability. Due to their number, diversity, and job creation capacity, SMEs serve as the backbone of the economy (Csutora and Kerekes, 2004; Luchsinger, 2024).

Obi et al. (2018) emphasize that the dynamism and flexibility of the SME sector, stemming from their smaller size, enhance national competitiveness and foster economic growth. Studies have also underscored that, in addition to their agility, SMEs are frequently a source of innovation (Gray and Jones, 2016; Langwell et al., 2023; Nwokocha and Nwankwo, 2019). The role of SMEs is particularly crucial in bolstering local economies and bridging social disparities, as they often operate in regions where the presence of large corporations is minimal. Furthermore, as suppliers to larger companies and key players within the supply chain, SMEs have a significant influence on broader economic ecosystem. Xu et al. (2020) illustrate that sustainability efforts by even a single actor within the supply chain can have a cascading effect, influencing other participants. Das et al. (2020) provide a detailed compilation of international studies on sustainability practices across various countries, discussing the driving forces behind sustainability as well as regulatory and ownership-related considerations.

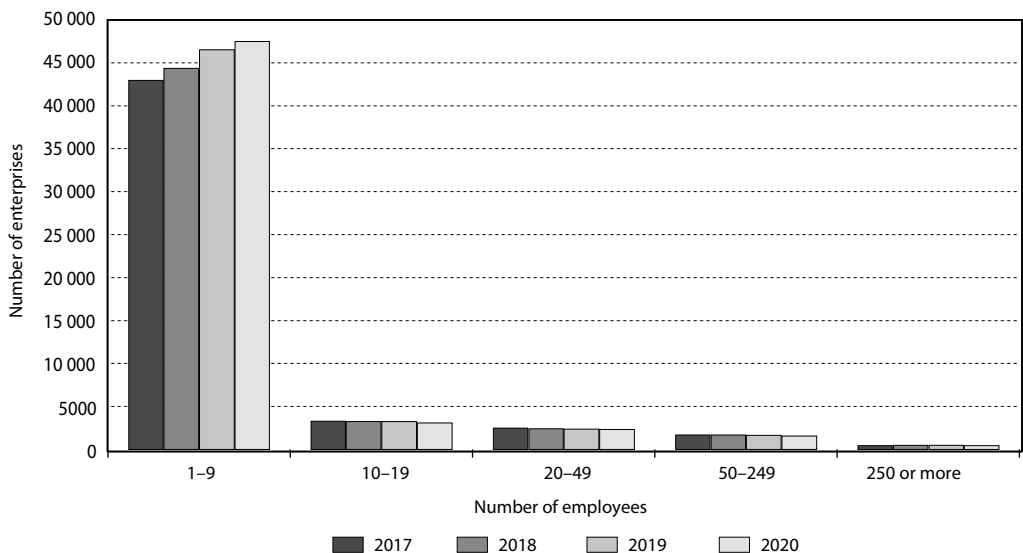
Beyond the aforementioned challenges, SMEs may encounter additional difficulties when integrating sustainability principles into their corporate operations. Jiang et al. (2023) underscore that efficient integration of these principles is crucial for the long-term survival of SMEs. Despite this, many SMEs, particularly those in developing countries, are slow to adopt sustainability practices. According to Nagypál (2014), Buhr (2017), and Jiang et al. (2023), this hesitation is often due to a lack of necessary tools, knowledge, and motivation to implement effective environmental, social, and governance (ESG) processes and natural resource management plans. Consequently, poor sustainability performance can lead to reputational damage and regulatory compliance issues, which erode the trust and credibility of SMEs. Therefore, it is an imperative for SMEs to initiate sustainability efforts that align closely with their corporate culture and unique characteristics, as the failure of such initiatives could jeopardize the entire business.

Most research focusing on SMEs tends to concentrate on small and medium-sized enterprises, often neglecting the unique challenges faced by micro-enterprises (Thaker, 2018). Micro-enterprises, typically defined as having fewer than 10 employees and an annual turnover of no more than 2 million euros, contribute significantly to the national economic development, despite their lower gross added value per company compared to medium-sized enterprises. These micro-enterprises play a vital role in integrating

local resources into the supply chain, alleviating poverty, and creating new social opportunities, including community engagement, income generation, and stable wealth accumulation (Thaker, 2018; Thaker et al., 2021).

According to Thaker et al. (2021), micro-enterprises constitute approximately 70% of businesses in most countries, contributing around 60% of total employment. OECD data (Figure 1) indicate that in Hungary, the proportion of micro-enterprises is even higher, ranging from 85–86% (OECD, 2023). However, it is crucial to acknowledge that ensuring and sustaining the operational stability of micro-enterprises remains a significant challenge globally (Thaker, 2018; Thaker et al., 2021). These challenges encompass high transaction costs, information asymmetries, insufficient legal protection (Dhingra and Sardana, 2024), inadequate financial resources and expertise, subpar corporate training frameworks, and inflexible financing structures. Collectively, these factors can impede the long-term success of micro-enterprises.

Figure 1 The change of the number of Hungarian micro-enterprises between 2017 and 2020



Source: OECD (2023)

The economic and social significance of micro-enterprises, as well as the challenges surrounding their operation, underscores that their success is contingent not merely on internal dynamics but also on fostering close and effective collaboration with stakeholders. To meet sustainability objectives, it is imperative that stakeholders – including employees, customers, and others – are recognized for their pivotal roles and integrated into the corporate decision-making processes. Engaging stakeholders in sustainability management is crucial not only for enhancing the competitiveness and stability of micro-enterprises but also for advancing sustainable economic development and bolstering social responsibility.

1.1 Role of stakeholders in corporate sustainability management

In the contemporary corporate landscape, stakeholder relations are becoming increasingly complex, with stakeholders exerting growing influence over companies. This trend is further intensified by society's heightened demand for transparency and access to relevant information. The proliferation of diverse communication channels has facilitated a faster and more efficient flow of information, enabling

stakeholders to stay informed in real time about current trends and challenges, including companies' sustainability initiatives and decisions (Marimbaldo-Callejo, 2020).

Recently, the focus on sustainability has surged, not only within society but also among market participants (Figure 2). This escalating attention is anticipated to place an increasing pressure on companies, particularly on the managers and owners of micro, small, and medium-sized enterprises. Recent research underscores that the identification of stakeholders and acknowledgment of their influence significantly impact corporate sustainability management (Schaltegger et al., 2019; Freudenreich et al., 2020; Wang et al., 2022; Valentinov, 2023). Failure to adequately monitor the broad spectrum of stakeholder needs raises the risk of management neglecting sustainability considerations. Valentinov (2023) highlights that examining corporate sustainability necessitates an understanding of stakeholder theories, especially concerning their relationship to corporate commitment. Sustainability strategies developed in collaboration with stakeholders can foster innovative processes that might not otherwise emerge. Costanza (2020) emphasizes that the successful development and implementation of sustainability strategies require the integration of three key elements: corporate vision, methodologies and analyses, and implementation. The latter includes formulating a sustainability-oriented corporate strategy, revising partnership selection and collaboration processes as needed, and continuously monitoring and responding to stakeholder feedback.

Rasche et al. (2023), Freudenreich et al. (2020), and Hörisch et al. (2014) concur that successful sustainability initiatives hinge on the accurate identification and comprehensive understanding of stakeholders, along with a precise definition of sustainability. While it is not necessary for the company and its stakeholders to interpret sustainability identically, for effective sustainability initiatives, companies must be acutely aware of stakeholders' perspectives on sustainability.

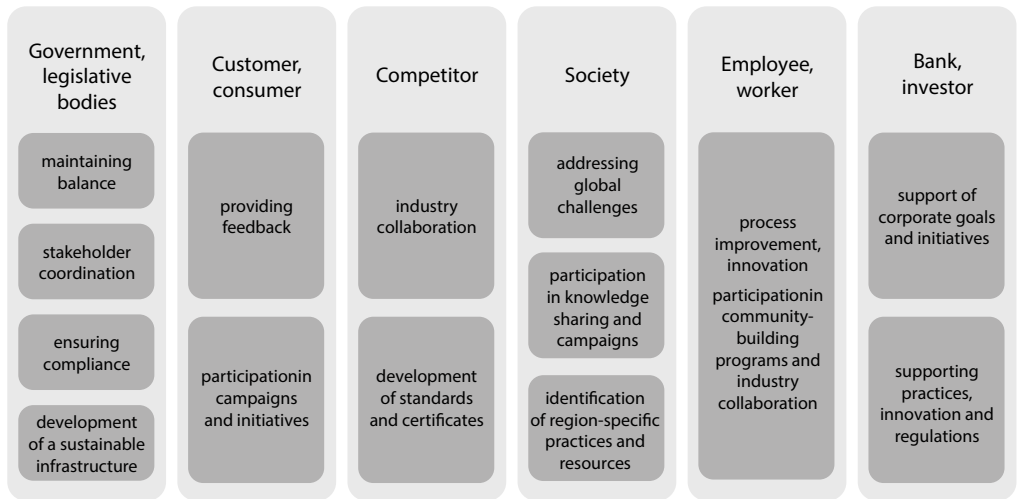
Rasche et al. (2023) underscore that corporate sustainability management revolves around balancing a company's integration within environmental, social, and economic systems to secure long-term positive outcomes, such as ecological equilibrium, social welfare, and stakeholder value creation. Costanza (2020) argues that sustainability cannot be effectively managed through conventional tools and best practices alone; instead, it demands a shift toward reorientation and systemic thinking (Roth, 2019; Jackson, 2019). Both theoretical and practical approaches must extend beyond the traditional economic and stakeholder paradigms, recognizing that each stakeholder perceives and values sustainability in a unique, individualized manner (Nelson, 2013; Nagyné Halász et al., 2023). According to Freeman et al. (2018), primary and secondary stakeholder groups exhibit distinct attitudes toward various operational domains of a company, including sustainability initiatives, which may be either company-centric or extend beyond the company's immediate interests. Valentinov (2023) highlights that primary stakeholders offer highly valuable contributions to company-oriented sustainability processes, while secondary stakeholders are pivotal in driving initiatives that are not directly related to the company's core operations. Das and Rangarajan (2020) note that, although regulatory pressures, transparency requirements, and stakeholder demands often serve as catalysts, the predominant driving force behind SMEs' commitment to responsible, sustainability-focused business practices frequently stems from intrinsic motivations.

Based on the work of Valentinov (2023) and Ginigea et al. (2018), Figure 2 outlines the primary categories of corporate stakeholders and the nature of sustainability pressures they exert on organizations.

Cultivating strong relationships with stakeholders serves as a powerful mechanism for the decentralized dissemination of sustainability-related knowledge (Van Assche et al., 2020). Freudenreich et al. (2020) and Schaltegger et al. (2019) argue that stakeholders' attitudes and their capacity to create value are pivotal in shaping organizational strategies, directly influencing the sustainability initiatives companies pursue, both in terms of direction and intensity. Valentinov (2023) asserts that achieving corporate sustainability hinges on effective collaboration between stakeholders and the company, with managers

playing a crucial role. These managers are tasked with ensuring that the company's activities do not adversely impact stakeholders. Such managerial diligence necessitates the continuous monitoring of stakeholder perspectives and well-being, the careful collection and balancing of pertinent information, and the alignment of structural features with diverse objectives (Payán-Sánchez et al., 2022). Accordingly, our research focuses on the sustainability pressures exerted by stakeholders, with special emphasis on the perspectives of managers within micro-enterprises.

Figure 2 Sustainability pressure exerted by organizational stakeholders



Source: Own construction

2 RESEARCH METHODOLOGY

Our research focused on the micro-enterprises operating in Hungary. We targeted senior managers with a questionnaire, as decisions regarding improvement opportunities, corporate objectives, and sustainability initiatives are typically made at this level. For these objectives to be effectively integrated into a company's mission, vision, and strategy, the active involvement and commitment of top management is crucial (Miklian and Barkemeyer, 2020; Akadiri and Fadiya, 2013; Burawat, 2019; Ónodi and Répácki, 2022).

Data collection was conducted in the spring of 2022 using an online questionnaire focusing on one main area that is from which stakeholders the participating company leaders feel sustainability pressure on the organization. To compile the dataset, we distributed the questionnaire to 70 000 SMEs, randomly selected from the Hungarian organization OPTEN's company database. The dataset was subsequently refined and limited to micro-enterprises.

Based on the responses, we aimed to explore the following research questions:

1. Is there an interrelationship among the sustainability pressures exerted by the six key stakeholders on micro-enterprises?

To address this question, we sought to determine whether identifiable relationships exist between the sustainability pressures exerted by these six stakeholder groups on micro-enterprises. We employed cross-tabulation analysis, utilizing the chi-square test and Cramer's V. Through the chi-square analysis, we examined the significant nature of the relationships by considering the values of the Cramer's V to assess its strength. Cramer's V ranges from 0 to 1, where values close to 0 indicate no association.

2. Can distinct variable groups be identified based on the sustainability pressures perceived by micro-enterprises?

In examining the second research question, our objective was to ascertain whether stakeholder groups could be effectively categorized based on the sustainability pressures experienced by micro-enterprises.

Given the predominantly categorical (nominal, so far binary, i.e. 0 and 1 values) nature of the dataset, we employed a specialized form of principal component analysis (PCA) with optimal scaling and multidimensional scaling (MDS) (Meulman, 1998; Tapasco-Alzate et al., 2022). According to Madan and Madan (2019), this approach facilitates the reduction of observed variables into a smaller set of principal components or dimensions that capture the majority of the variance within the data. A key advantage of this method is its ability to accommodate both nominal (categorizable) and ordinal data (ranked), elucidate non-linear relationships among variables, and serve exploratory research purposes effectively. The application process demonstrated by Van der Geer (1993) and Andersen (2012) was followed in our analyses. For the calculations, we used the Microsoft SPSS 29 software, which allows for detailed analysis of categorical data.

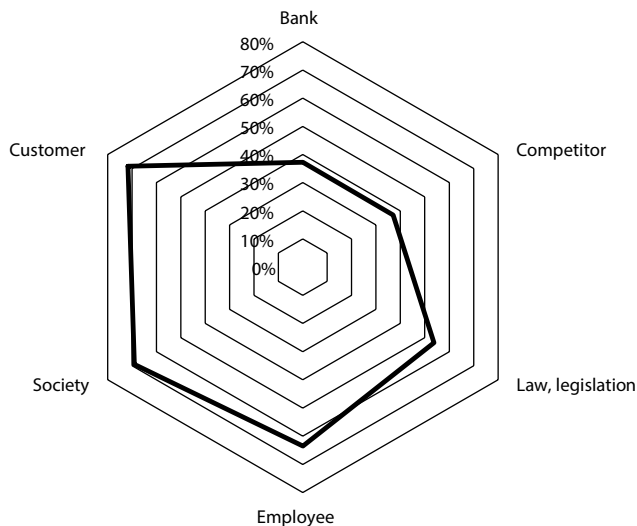
3 RESULTS

After the completion of data collection and subsequent data cleaning, we processed responses from 587 micro-enterprises. This sample size is considered adequate for surveys in the corporate sector and facilitates the formulation of robust research findings (see, e.g., Ónodi and Répácki, 2022; Vörösmarty and Dobos, 2020; Chikán et al., 2019).

80% of the top managers who participated in the survey were aged 43 years or older, from which we assume that they are managers with extensive experience. Additionally, 52.8% of the surveyed companies were founded within the past 16 years, and 98.5% are entirely Hungarian-owned. While all industry sectors were represented in the sample, the distribution is uneven, which precludes the sample from being considered fully representative; consequently, no sector-specific analyses were performed.

Figure 3 illustrates the proportion of Hungarian company managers who perceive pressure from various stakeholders to initiate sustainability efforts. The data reveals that managers primarily feel this influence from customers, society, and employees. There is also substantial pressure from regulatory bodies, particularly concerning the expansion of sustainability reporting requirements.

Figure 3 Micro-enterprises' perception of sustainability pressure from the surveyed stakeholders

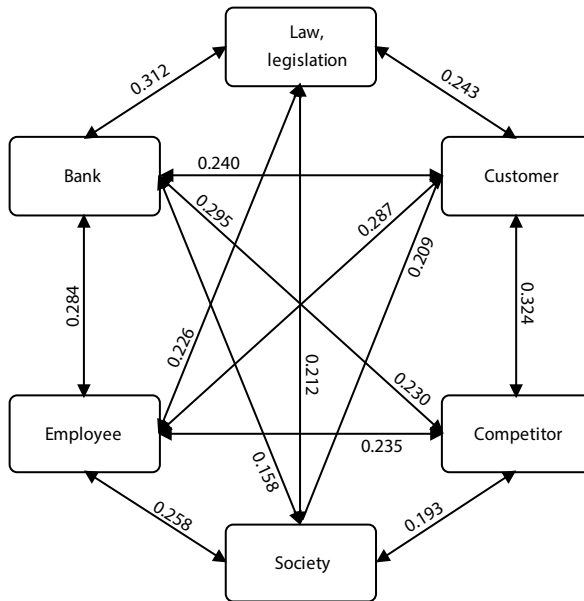


Source: Own construction

3.1. The interrelationship among the sustainability pressures exerted by six key stakeholders on micro-enterprises

To investigate the 1st research question, we conducted a cross-tabulation analysis to identify potential relationships between the sustainability pressures perceived from the six stakeholder groups. The results of the cross-tabulation analyses are presented in Figure 4. In all instances, the observed significance levels, p-values were below 0.05, indicating a statistically significant relationship in the perceived sustainability pressures emanating from the six stakeholder groups.

Figure 4 Results of cross-tabulation analysis with Cramer’s V values based on the pressure exerted by the various stakeholders



Source: Own construction

According to the Cramer’s V values, a moderately strong association can be identified in all cases, except for the relationship between society and banking. The relationship between the society and the competitor side can be considered approximately medium. The strongest relationship appears between the competitor and customer, as well as the legal and banking stakeholder sides.

3.2. The distinct variable groups based on the sustainability pressures perceived by micro-enterprises

For the 2nd research question, we explored potential groupings of variables using optimal scaling and MDS. Through optimal scaling, data are condensed, enabling the creation of fewer than the original six dimensions. The values presented in Table 1 indicate the degree of association between the categorical components derived from optimal scaling and the binary variables, reflecting the extent of discrimination. These findings suggest that it is advantageous to categorize the variables into three distinct groups:

- The first group encompasses pressures exerted by customers, competitors, employees, and banks.
- The second group is characterized by societal pressure.
- The third group pertains to legal and legislative pressure.

This classification provides a structured understanding of how different stakeholders influence sustainability efforts within micro-enterprises.

Table 1 Components of the optimal scaling algorithm

Pressure	Component 1	Component 2	Component 3
Law, legislation	0.366	0.033	0.323
Customer	0.408	0.001	0.223
Competitor	0.397	0.062	0.172
Society	0.270	0.555	0.022
Employee	0.397	0.060	0.002
Bank	0.403	0.165	0.074
% of variance	37.359	14.584	13.611

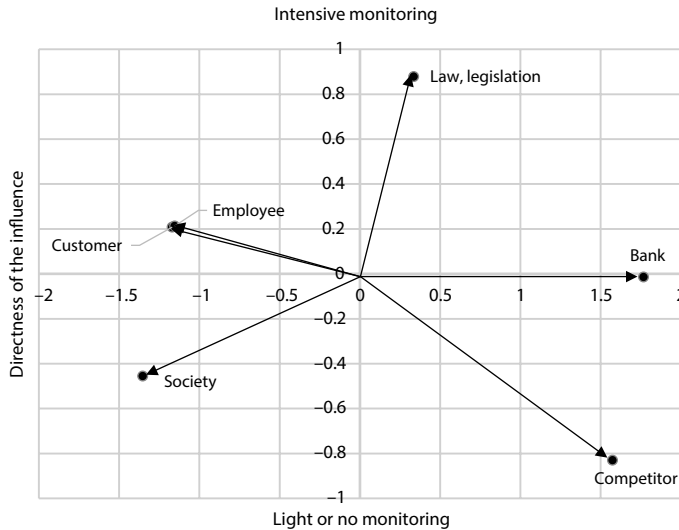
Source: Own construction

The first group consists of stakeholders who primarily exert influence through demand-related factors. The sustainability pressures from these stakeholders are largely shaped by the ongoing evolution of market demands and expectations, which encompass customer requirements, competitive forces, employee aspirations, and financial performance metrics. The second group is dedicated to social impact and corporate responsibility. The distinction of this group from the others lies in its representation of a more advanced concern that transcends market-driven dynamics, focusing instead on broader societal responsibilities. The third group is primarily concerned with ensuring compliance with regulatory and legal standards. Although the degree of association of “law and legislation” with the first group is slightly higher than with the third group (as shown in Table 1), the decision to assign it to the third group is conceptually justified. Laws and legislation are fundamentally distinct from the pressures exerted by customers, competitors, employees, and banks (Component 1), which are more immediate and business-driven influences. Instead, “law and legislation” aligns more closely with external regulatory forces, which define the nature of Component 3.

To further explore the 2nd research question, we conducted a MDS analysis. This method involves projecting our data from a six-dimensional space into a two-dimensional space, wherein the relative proximity of the variables is represented by a set of distances in the reduced-dimensional space. Our objective is to maintain the fidelity of the original distances as accurately as possible within the lower-dimensional representation. This means that the spatial arrangement of the points in the two-dimensional plot should closely mirror the actual relationships present in the original six-dimensional data. The analysis yielded a high coefficient of determination (R^2) value (0.99887), indicating a robust correlation between the distances in the six-dimensional and two-dimensional spaces. Additionally, after 20 iterations, the stress level – a measure of the goodness of fit – was 0.01524, as calculated using Kruskal’s stress Formula 1, proposing an excellent fit of the model to the data.

The MDS analysis suggests that sustainability pressures on companies can be interpreted along two principal dimensions (Figure 5). The first dimension represents the directness of the influence, while the second dimension reflects the intensity of monitoring required.

Figure 5 Results of MDS analysis demonstrating the stakeholders based on the directness of the influence and the monitoring aspects



Source: Own construction

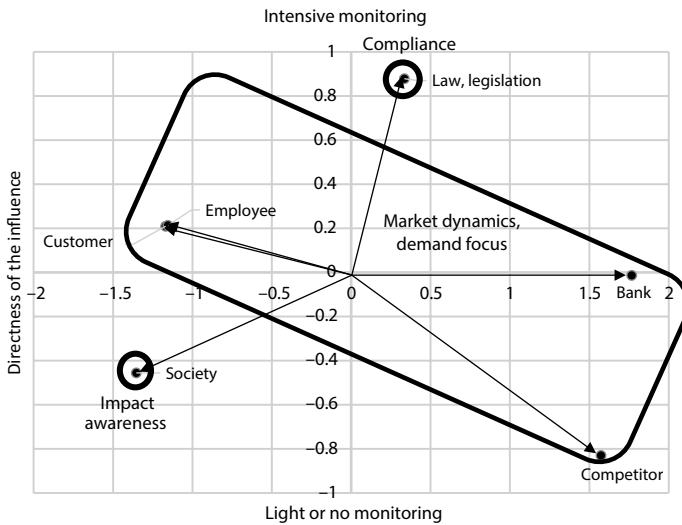
The first dimension (vertical axis) highlights the extent to which micro-enterprises need to, or are able to, consistently monitor the sustainability practices and impacts of various stakeholder groups. Given their typically limited resources, time, and capabilities, micro-enterprises must prioritize monitoring areas that have immediate implications for their day-to-day operations, such as resource constraints, prioritization of daily tasks, and risk management. For these companies, keeping up-to-date with legislative changes (e.g., tax regulations, sustainability standards) is critical, as non-compliance could result in substantial fines. Micro-enterprises must maintain vigilant oversight of customer and employee satisfaction, as even minor shifts can have outsized impacts due to their small scale. For instance, losing just one or two customers can lead to severe financial strain, and any discontent among employees can disrupt business continuity given their typically small workforce. In contrast, engagement with banks, while significant due to financial obligations, credit terms, and financing conditions, tends to be periodic rather than continuous. Interactions are generally linked to specific financing periods rather than daily operations. Similarly, while tracking societal expectations, norms, and trends is beneficial, micro-enterprises often lack the capacity for continuous monitoring in these areas, as such changes tend to exert a more indirect and long-term influence on their business activities. Competitor analysis, although strategically important, is not typically a daily priority for micro-enterprises. Such analysis is often conducted at specific intervals, such as during the launch of new products or shifts in market trends, rather than as part of everyday operational focus (if they deal with it at all).

The second dimension illustrates the degree of directness and structure in stakeholder influence on a company's operations. In this context, stakeholders such as society, customers, and employees exert a more direct impact, whereas competitors and banks exert a relatively indirect influence. Although societal pressure may initially seem less direct, it plays a critical role in shaping the corporate image, which is of paramount importance to organizations. This suggests that a company's perceived social standing can significantly drive its behavior beyond mere corporate "vanity." Legal and regulatory pressures, meanwhile, can operate on both direct and indirect levels. The horizontal sustainability supply chain also partially manifests within this dimension.

By integrating the results of optimal scaling with the findings from the MDS analysis (Figure 6), it becomes evident that legal sustainability pressures are immediately apparent to micro-enterprises, as it has the highest value on the vertical axis. However, the process of interpreting and incorporating these regulations into daily operations often presents challenges (shown on the horizontal axis), as these legal frameworks are not typically designed with the nuances of micro-enterprises in mind. While societal expectations exert a direct influence (horizontal axis), micro-enterprises often lack the capacity and resources to continuously track and adapt to evolving societal trends (vertical axis).

On the demand side, the interplay between customers, employees, banks, and competitors is highlighted. Micro-enterprises closely monitor customer and employee needs (vertical axis), recognizing that the organization must be agile enough to respond to shifts in their expectations. Although the influence of banks and competitors may be more indirect (horizontal axis), their impact reverberates through the organization, ultimately affecting both employees and customers. Thus, even indirect pressures can translate into significant operational adjustments, underscoring the interconnectedness of stakeholder influences within the company's ecosystem.

Figure 6 Relationship between MDS and optimal scaling results



Source: Own construction

CONCLUSION

In this study, we have identified the key stakeholders influencing Hungarian micro-enterprises and explored the dynamics of sustainability pressures exerted by these groups. Our research sought to determine which stakeholders apply sustainability pressures on micro-companies and how these pressures are interrelated. We found that government, through legal regulations, act as significant drivers of sustainability efforts, while societal values also play a crucial role. Other stakeholders, such as customers, employees, competitors, and banks, either amplify or moderate these sustainability efforts, further shaping the sustainability landscape of these companies.

We categorized stakeholders into three main groups based on the nature and intensity of sustainability pressure. The first group includes customers, employees, competitors, and banks, which exert direct or interconnected influences on companies. The second group comprises societal pressures, reflecting broader social values and expectations. The third group is characterized by legal and regulatory

pressures imposed by governmental bodies. Each group presents distinct strategic challenges for micro-enterprises, such as prioritizing stakeholder expectations, monitoring trends, and ensuring compliance with evolving standards.

Our findings underscore the importance of a collaborative approach between stakeholders and micro-enterprises. Effective strategic decision-making, which aligns with stakeholder interests, can create mutually beneficial outcomes, supporting both sustainability and competitiveness (Valentinov, 2023). Sustainable corporate strategies must be deeply integrated across all levels of the organization, guided by management's commitment to harmonizing profit generation with environmental and societal values (Baumgartner, 2014; Bon and Fisher, 2011). The role of management is crucial in not only formulating but also in implementing such strategies, ensuring that the company's sustainability efforts are coherent and impactful.

The results also highlight that stakeholder pressures vary significantly in their nature and intensity. It is imperative for managers to recognize these differences and adopt tailored responses to each type of pressure. For instance, the response required for employee and customer expectations may differ substantially from that required for legal compliance or financial considerations. Drawing on insights from optimal scaling and MDS analysis, managers must strategically prioritize among stakeholders who influence the company through legal frameworks, societal values, or competitive and financial dynamics. This prioritization enables companies to focus their sustainability initiatives on areas that yield the most substantial social and economic benefits, while also maintaining the flexibility to adapt to shifting stakeholder demands.

Continuous and proactive engagement with stakeholders is essential, as changes in stakeholder expectations can significantly influence a company's strategic direction and sustainability efforts (Freudenreich et al., 2020; Schaltegger et al., 2019; Payán-Sánchez et al., 2022), and as the results show, opposite direction is also true. In the case of micro-enterprises, their organization strategy and their connected monitoring processes fundamentally influences which stakeholder has the most direct effect on them. By fostering an ongoing dialogue and collaboration with stakeholders, companies can better navigate these complexities, ensuring that they remain resilient and responsive in a rapidly changing environment. This collaborative approach not only enhances the company's capacity to meet diverse stakeholder expectations but also strengthens its overall sustainability performance and social responsibility.

However, the limitations of our research should be acknowledged. The findings are based on a specific set of data collected from Hungarian micro-enterprises, and further studies could broaden the scope to include diverse industries and geographical contexts. Future research should also consider longitudinal analyses to capture the evolving nature of stakeholder pressure and their long-term impact on micro-enterprise sustainability strategies.

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Public Expenditures in the Education and Health Sector and Their Impact on Economic Development – the Case of the Republic of Kosovo

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Abstract

The purpose of this paper is the analysis of public expenditures in the education and health sectors in relation to economic development in Kosovo. The work is carried out with the quantitative methodology, which is based on secondary data. The research covers a long-term period with the data from 2000 to 2023. In the analysis of the impact of public spending in the education and health sector on the economic growth of Kosovo, the Autoregressive Distributed Lag (ARDL) model was used, which deals with time series data, in a long-term period of 24 years. Findings from the research show that public spending supports the hypothesis that the policy of public spending on education positively affects the economic growth of Kosovo, emphasizing the importance of sustainable investments in educational initiatives for long-term economic development. However, these findings do not provide sufficient support for the hypothesis that the public health spending policy significantly contributes to the economic growth of Kosovo.

Keywords

Economic development, education and health sector, public expenditures, Republic of Kosovo

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INTRODUCTION

Many authors have addressed topics related to public spending in the education and health sectors, as well as their impact on the economic development of different countries and different periods of time. The process of economic development of a country represents the measure of improving people's well-being or socio-economic development. The importance of public spending is in the long-term result and the long-term impact they will have on the economy. The economic development of Kosovo has faced many challenges in its journey as an independent state in the management of public expenditure policies of sectors with importance and impact on the country's development. Most studies report that economic development requires a sustainable policy of the health sector and the education sector within the country (Han, 2021; Qehaja, et al., 2022; Yfantopoulos, 2024). Researches show the necessity for the Kosovo government to give priority to the distribution of sufficient and effective health care funds in order to meet the needs of the population, effective and sufficient funds in the education sector in order to improve rankings within local and international institutions. Kosovo is characterized by the lack of educational and health policies, which has consequences in the proper functioning of these two very important sectors, and the lack of these policies creates challenges for sustainable economic development. Challenges which are closely related to the reformation of the country after the conflict with Serbia (Han, 2021; Kryeziu and Coşkun, 2018; Mansi et al., 2020).

This paper aims to analyze the role of public expenditure policies in the economic development of the country. This study offers the view on how the policies of Government Expenditure on Education (GSE) and Government Expenditure on Health (GSH) affect the economic development of Kosovo, during a long-term period with data from 2000 to 2023, i.e. 24 years research period. The economic challenge of managing expenditure policies in education and health offers us strategies for sustainable economic development. By increasing the management and quality of these sectors, Kosovo will be able to mark a country with better prospects by offering education and health at a better level. This will have a positive impact on improving social well-being, the standard of living, the level of education, reducing the trend of brain drain or professional medical and educational staff as the biggest challenge in recent years.

The main objective of this paper is to present the impact of public spending on the economic growth of Kosovo, where the research provides a statistical analysis through quantitative methodology, which is based on secondary data.

The research questions of the paper are:

1. What is the role of public education expenditures in the economic development of Kosovo?
2. What is the role of public health expenditures in the economic development of Kosovo?

While the research hypothesis are:

- H1: The policy of public spending on education has a positive impact on the economic growth of Kosovo.*
H2: The public health expenditure policy has a positive impact on the economic growth of Kosovo.

To evaluate the presented hypotheses, the Autoregressive Distributed Lag (ARDL) model was used. This model was chosen because of its ability to handle time series data, which spans a long-term period of 24 years, from 2000 to 2023. The data used in this study belong to the type of time series data since we have only one country that has been included in the empirical statistical analysis for a long period of time (24 years). The empirical analysis was based on the data from the Statistics Agency of Kosovo and the Ministry of Finance. The paper analyzes the role of public expenditure management in education and health in improving the standard of living and general development.

The paper is structured in six chapters, where the following part presents the literature review. The third part of the study contains the methodology, the fourth part presents the empirical results, the fifth part includes the discussions and the final part the conclusions and recommendations from the results.

1 LITERATURE REVIEW

Numerous studies by authors from different countries address the impact of public spending policies on education and health on the economic development of different countries. Based on the findings, many authors also research the impact of public education and health spending policies on the economic development of the Republic of Kosovo. Below are presented some of the views of the studies on the impact of public spending on the economic development of different countries, especially Kosovo. The study by Martins and Veiga (2014) concluded that the composition of public expenditures had an impact on development. While in their analysis Barilee and Leyira Christain (2021) point out that education expenses are viewed critically and that the government should devote more resources to education, while the operation of the health sector has an advantage for economic development. The research of Montenegro and Shenai (2019) provides the main findings that spending on education contributes to economic development and subsequently to economic growth. According to the research carried out by the authors Manullang et al. (2024) there is an evidence that public spending on health and education is the main fiscal instrument to improve the quality of life of citizens, which contributes to human development. While the study of West African countries by Ogbonnaya-Udo and Chukwu (2020) asserts that government spending has an insignificant but positive effect on economic development (represented by the human development index) and recommends that spending on education, health and security should be increased and that these funds should not end up in private pockets.

Percival and Sondorp (2010) measure the success of health reforms in Kosovo accomplished with the help of the international community aimed to rebuild health systems in post-conflict periods, concluding that there are measures that have not been systematically examined. In the analysis, the paper demonstrates that the external nature of the reform process, the compressed time period for the reform and the weak state capacity are factors that minimized the success of the reform program. A research carried out by the authors Qehaja et al. (2022) for the countries of the Western Balkans shows that there is a positive and statistically significant relationship between government spending and economic development. The study finds that the coefficient for government spending on education is positive, while the coefficient on government spending on health is negative. Kryeziu and Coşkun (2018) analyzed that Kosovo faced challenges of imbalances in the distribution of power and illegitimacy of governing institutions during the period of state building administered by international organizations. In the post-independence period, in the ongoing political tension between local parties, efforts to create functioning institutions have not yielded good results and that Kosovo has not been able to create a functional economy and overcome economic challenges. The Han (2021) study on the education and health sector and reforms after the conflict with Serbia claims that Kosovo's weak education system, as a result of overcrowding in schools, where students do not have personalized teaching, results in stressed students and teachers which, consequently, produce low rankings. Poor funding for schools and hospitals, poor work standards and low salaries for teachers, are some of the examples of reforms in improving unfavorable conditions such as the lack of equipment in schools and hospitals in Kosovo. The research conducted by Bartlett (2009) shows that conflicts in the Western Balkan region were characterized by deindustrialization and high unemployment, political unrest, instability, etc. The paper argues that low inflows of international capital, due to high country risk, have hindered technological achievement and weakened international competitiveness and therefore economic development follows a path of low-skill growth. The research Mansi et al. (2020) asserts that from the economic growth of recent years that the countries of the Western Balkans have shown, we notice that the poverty rate and income inequality have marked a great decrease. The paper further highlights that governance and unemployment, the investment environment, innovative capacities are the main factor in reducing the poverty rate, income inequality and thus contribute to sustainable development. Making comparisons in the European Union and the countries of the Western Balkans, the study argues that income inequality and economic growth affect the poverty rate. However,

factors that contribute to the poverty rate for both cases are governance and unemployment, while the investment environment and education will change based on the economic growth and political stability of the countries. Popović, and Erić (2018) estimate that high rates of economic growth require continuous investment, from investment sources that are national savings and foreign investments. The study asserts that the national level of savings in the Western Balkans is not sufficient to finance radical changes, so external resources, especially foreign direct investment, are necessary for further development. The findings of the study Arenliu Qosaj and Bourdeaux (2024) provide the measurement of the change in the health outcomes of the countries of the Western Balkans alongside the health policies recommended by the EC related to the EU membership. The study shows that from 2000 to 2019, citizens of Western Balkan countries paid more and their governments paid less for health care. The governments of Albania, Kosovo, Montenegro and North Macedonia spent less than the recommended minimum of 5% of their GDP on healthcare. The study shows increasing trends in healthcare professional rates but remains lower than the EU average and may be exacerbated by healthcare workforce migration. The study concludes that addressing the growth of health human resources, especially for Albania and Kosovo, deserves attention. The authors Musah et al. (2024) analyze the short- and long-term effects of public education funding on the quality of education in sub-Saharan Africa. They claim that the education sector plays an important role in improving the welfare of society, which is why governments invest large sums of money in education. The findings of their study show that increased spending on public education improves the quality of education in sub-Saharan Africa in the short and long term. They recommend that the country should make sufficient budget allocations to improve educational quality. Li et al. (2024) presents a relationship between the coordinated development of spending on public education, the accumulation of human capital and economic growth which is a prerequisite for the virtuous cycle of regional economic development. The authors recommend that the Chinese government should establish a long-term mechanism to ensure a certain level of investment in public education in the future, which is essential for the accumulation of human capital. Yfantopoulos (2024) shows that Southern and Central Eastern European countries need policy interventions to improve access and health outcomes. The findings indicate that public health interventions should be undertaken by International Organizations and National Governments to bridge the gap in health investment, improving access, addressing health inequalities and reducing the burden of high payments for medicines and health care services.

2 RESEARCH METHODOLOGY AND DATA

In order to analyze public expenditures and the impact of public expenditures in two important sectors of the economy; the education and health sector in the economic growth of Kosovo, the quantitative methodology, which is based on secondary data, has been used. So, the research includes only the Republic of Kosovo in a long-term period with the data from 2000 to 2023, i.e. 24 years research period. Since only one country is included in the empirical statistical analysis, while the data are over a long period of time (24 years), then the data are characterized by the type of time-series data. Where these 24 years are the maximum data available for the state of the Republic of Kosovo.

In the analysis of the impact of public expenditures in the education and health sector on the economic growth of Kosovo, the Autoregressive Distributed Lag (ARDL) model was used. This model was chosen because of its ability to handle time-series data, which spans a long-term period of 24 years, from 2000 to 2023. The quantitative methodology based on secondary data has allowed the examination of short-term interactions. and the long-term relationship between public spending and economic growth, providing a deep understanding of the impact of the education and health sectors. The data for the research were obtained from the Statistics Agency of Kosovo (ASK) and the Ministry of Finance, Labor and Transfers (MFPT), where the study data is characterized by the type of time series data. The ARDL model is suitable

for this analysis because of its flexibility in handling the integration of different variables and providing accurate results even when the variables have different levels of integration.

The model is defined as follows:

$$GDP_t = \beta_0 + \beta_1 GSE_t + \beta_2 GSH_t + \varepsilon_t. \quad (1)$$

The ARDL model for the study specified as:

$$\Delta GDP_{t-1} = \beta_0 + \beta_1 GSE_{t-1} + \beta_2 GSH_{t-2} + \varepsilon_t. \quad (2)$$

The dependent variable of the study is the economic growth (GDP), while the two independent variables of the study are; government expenditure on education (GSE) and government expenditure on health (GSH). The parameters β_1 , and β_2 represent the elasticities of the variables in the model in relation to economic growth, t represents time and ε is the error term. To ensure the robustness of our time-series analysis, we utilized the Augmented Dickey-Fuller (ADF) test to examine the stationarity of the data series for GDP, government spending on education (GSE), and government spending on health (GSH) over the 24-year period from 2000 to 2023. The ADF test is a widely used statistical test that helps determine whether a time series is stationary or contains a unit root, indicating non-stationarity. Stationarity is a crucial property for time-series data as it implies that the statistical properties of the series, such as mean and variance, are constant over time, ensuring reliable and consistent model estimations. By applying the ADF test, we can identify the order of integration for each variable, which is essential for the correct specification of the ARDL model. The test involves estimating a regression and checking if the lagged level of the series significantly influences its first differences, allowing us to distinguish between variables that are stationary at level ($I(0)$) and those that require differencing to become stationary ($I(1)$). This step is pivotal in confirming the appropriateness of the ARDL model for our analysis, as it can handle variables integrated at different levels, thus providing accurate insights into the short-term and long-term impacts of public expenditures on education and health on Kosovo's economic growth.

Table 1 Definition of variables

Nr.	Variable	Type	Unit
1	Economic growth	Dependent	%
2	Government expenditure on education	Independent	% of Gross domestic product
3	Government expenditure on health	Independent	% of Gross domestic product

Source: Authors

3 EMPIRICAL RESULTS

The GDP data for the Republic of Kosovo from 2000 to 2023 reveals a pattern of economic variability, marked by periods of both significant growth and contraction. In the early 2000s, Kosovo experienced moderate GDP growth, with a notable exception in 2002, where the GDP contracted by 0.70%. This was followed by a period of substantial growth from 2005 to 2008, reaching a peak growth rate of 7.29% in 2007. The global financial crisis in 2008 led to a deceleration in growth, with the GDP growth rate reducing to 3.60% in 2009 and further to 3.31% in 2010.

The post-crisis period saw a series of fluctuations, with the GDP growth rate generally hovering between 2.81% and 4.38% from 2011 to 2018. Notably, there was a significant slowdown in 2014, with growth reducing to 1.22%. Despite this, the economy showed resilience, recovering to a growth rate of 4.94% by 2019. The COVID-19 pandemic had a severe impact on Kosovo's economy in 2020, resulting in a contraction of 6.89%. However, the economy rebounded strongly in 2021 with a remarkable growth rate of 10.70%, indicative of a robust recovery phase. This recovery was followed by a stabilization period with growth rates of 5.20% in 2022 and 3.05% in 2023.

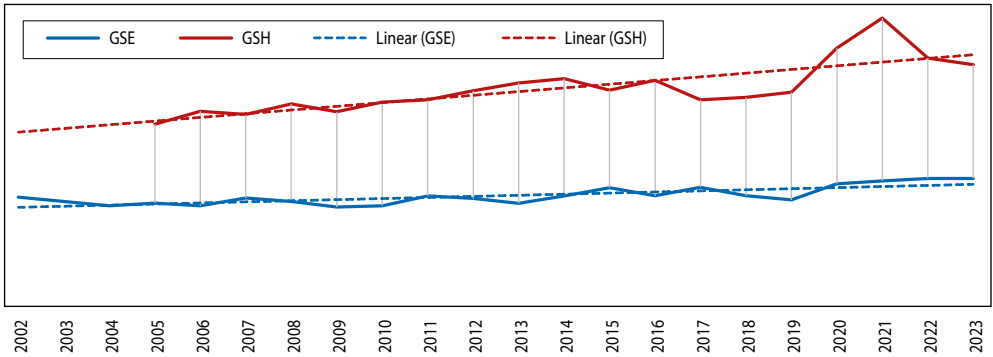
Table 2 Data for economic growth, government spending on education and health in Kosovo (2000–2023)

Year	GDP	GSE	GSH
2000	26.90		
2001	26.97		
2002	-0.70	4.15	
2003	5.98	3.98	
2004	2.61	3.80	
2005	6.03	3.91	7.14
2006	4.50	3.80	7.67
2007	7.29	4.12	7.54
2008	6.30	3.98	7.97
2009	3.60	3.75	7.65
2010	3.31	3.80	8.05
2011	4.38	4.20	8.14
2012	2.81	4.10	8.51
2013	3.44	3.90	8.83
2014	1.22	4.20	9.01
2015	4.10	4.54	8.54
2016	4.07	4.21	8.94
2017	4.23	4.56	8.14
2018	3.81	4.21	8.24
2019	4.94	4.04	8.45
2020	-6.89	4.70	10.26
2021	10.70	4.82	11.49
2022	5.20	4.92	9.85
2023	3.05	4.92	9.58

Source: Statistics Agency of Kosovo

According to the results presented in the following figure, government spending on health is higher compared to government spending on education. In the period 2002–2023, we have positive growth trends for these two types of government spending, although the trend is more positive for health spending.

Figure 1 Comparison of government spending on health and education in the Republic of Kosovo



Source: Kosovo Statistics Agency, processed by authors

The average economic growth in the Republic of Kosovo during the period 2000–2023 is 5.74%, while regarding government spending, the average spending on education (2002–2023) is 4.21% of the gross domestic product, while the average government spending on health (2005–2023) is 8.63% of the gross domestic product value.

Table 3 Descriptive statistics of variables

Variable	Obs	Mean	Std. dev.	Min	Max
GDP	24	5.744	7.237	-6.888	26.974
GSE	22	4.21	0.372	3.75	4.92
GSH	19	8.632	1.061	7.14	11.49

Source: Authors calculations

The ADF test results reveal that the GDP series is stationary, implying stability and mean reversion over time. In contrast, both the Government Spending on Education (GSE) and Government Spending on Health (GSH) are non-stationary, indicating that these series are affected by permanent shocks and do not revert to a long-term mean. Understanding the stationarity of these series is crucial for economic modeling and forecasting, as it affects how past data can be used to predict future values and the nature of any interventions or policy measures.

Table 4 Augmented Dickey Fuller Test

Variables	Test Statistic	1%	5%	10%	MacKinnon approximate p-value for Z(t)
GDP	-4.609	-3.75	-3.00	-2.63	0.0001
GSE	-1.157	-3.75	-3.00	-2.63	0.6918
GSH	-1.743	-3.75	-3.00	-2.63	0.4089

Source: Authors calculations

The analysis of Government Spending on Education (GSE) reveals significant results. The model includes two lags for GSE. The first lag has a coefficient of 10.69 with a standard error of 1.08, resulting in a high t-statistic of 9.92 and a p-value of 0.064. Although this p-value is just above the conventional significance level of 0.05, it suggests that the first lag of GSE is quite influential. The second lag has a coefficient of 3.82, a standard error of 0.87, and a t-statistic of 4.37, with a highly significant p-value of 0.000. This indicates a strong effect of the second lag of GSE on the dependent variable, showing that past values of GSE significantly influence its current level.

For Government Spending on Health (GSH), the model also includes two lags. The first lag of GSH has a coefficient of 2.59 with a standard error of 0.59, leading to a t-statistic of 4.35 and a p-value of 0.144, which is not statistically significant at conventional levels. The second lag has a much smaller coefficient of 0.35, with a standard error of 0.61, yielding a t-statistic of 0.57 and a p-value of 0.671, indicating it is far from significant. These results suggest that past values of GSH do not significantly predict its current level, implying a weak lagged effect.

Table 5 Results of coefficients

Variables	Lags	Coefficient	Std. error	t-Statistic	Prob.
GSE	1	10.69	1.08	9.92	0.064
	2	3.82	0.87	4.37	0.000
GSH	1	2.59	0.59	4.35	0.144
	2	0.35	0.61	0.57	0.671
F				102.710	
Prob>F				0.077	
R-Squared				0.999	
Adj R-Squared				0.990	
Log Likelihood				14.370	
Root MSE				0.360	

Source: Authors calculations

4 DISCUSSION

The analysis of Government Spending on Education (GSE) in Kosovo suggests a significant relationship between education public expenditure policy and economic growth. Both the first and second lags of GSE exhibit notable coefficients, with the second lag showing a particularly strong effect on economic growth. Despite the first lag's p-value slightly surpassing the conventional significance level, its high t-statistic implies substantial influence. These findings support the hypothesis that education public expenditure policy positively impacts Kosovo's economic growth, emphasizing the importance of sustained investment in educational initiatives for long-term economic development. The view that government spending on education has a positive relationship with economic development is reinforced by the findings of the works (Qehaja et al., 2021; Montenegro and Shenai, 2019). Also, regarding the fact that the education

sector plays an important role in improving the welfare of society, and that the increase in spending on public education improves the quality of education in the short and long term, our results are similar to (Musah et al., 2024).

Analysis of Government Spending on Health (GSH) presents less compelling evidence regarding its impact on economic growth. While the first lag of GSH displays a coefficient suggesting a potential relationship, its statistical significance is marginal. Moreover, the second lag fails to demonstrate any significant effect on economic growth, indicating a weak relationship between past health spending policy and current economic performance. Thus, the results do not provide sufficient support for the hypothesis that public health spending policy significantly contributes to the economic growth of Kosovo. These results contradict the findings of Barilee and Leyira Christain (2021) that the functioning of the health sector means an advantage for economic development.

Although this research has offered a valuable knowledge to understand the dynamics of public spending in the two most important sectors, it shows the need for further studies to examine these relationships in more depth and to explore other possible influencing factors which are not addressed in this study. It can guide policy makers in formulating effective policies to manage the country's economic growth and development. For example, restrictive measures against the mismanagement of public spending, increasing public spending towards these sectors, especially in the field of education, in the most efficient way can encourage economic growth as well as economic development as a whole. If these policies are used in a strategic and effective way, they may raise the standard of living, the economic development of the Republic of Kosovo and the reduction of poverty.

CONCLUSIONS

The efficiency of public spending in the economic development of a country depends on the quality of institutions and governance with public spending, administrative corruption and the informal economy. The level of corruption and mismanagement of public spending is the evidence of low efficiency of government spending. The importance of public expenditure allocation lies in the fact that the government is able to ensure that capital expenditure and current expenditure are properly managed so that they increase the country's education and health capacity. The government should direct spending towards the most productive sectors for the economy: such as education and health, targeting projects that increase the level of health and education services. Kosovo needs stability and sustainable economic development of development sectors and increased institutional supervision in order to reduce the level of mismanagement of public money. Based on the findings of the paper, we conclude that good governance with public participation, the investment environment, and innovative capacities are the main factors that contribute to the long-term sustainable development and poverty reduction.

Furthermore, when we compare these two types of spending, we notice that government spending on health is higher compared to government spending on education. In the period 2002–2023, there were positive trends in the growth of both types of government spending, although the trend was more positive for health spending. The average economic growth in the Republic of Kosovo during the period 2000–2023 was 5.74%. As for government spending, the average spending on education (2002–2023) was 4.21% of the gross domestic product, while the average government spending on health in (2005–2023) was 8.63% of the value of the gross domestic product.

The results of this study in the Republic of Kosovo for a period of 24 years (2000–2023) reveal that the country's government must create long-term mechanisms to ensure a higher level of investment and monitoring in the education system, which is essential for economic growth (GDP) and economic development.

The paper has statistical support for the first hypothesis, "The policy of public spending on education has a positive impact on the economic growth of Kosovo" and also finds agreement with the findings

of other authors. But, without overlooking the interventions in the policies of the health sector and the improvement of care services and the increase of the health standard in general. Based on the results presented in the paper, we recommend that Kosovo should create long-term policies to generate jobs in the health system, policies to increase wages and reduce the rate of migration of the health workforce to EU countries.

Policy makers and stakeholders in the country can use these findings to address strategies aimed at promoting policies for the development of education, which is one of the key factors in the country's economic growth and development. Especially their statistically significant impact requires us to prioritize them and increase them in order to promote sustainable economic development and address economic challenges. On the other hand, the importance of Government Expenditures for Health is seen as a need for policy intervention to improve the results in the health sector, reduce the mismanagement of services and health care, which would result in the improvement of the health standard in general and the reduction in the migration rate of the country's health workforce.

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Composite Indexes for Measuring Destination Competitiveness of Italian Regions

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Abstract

As tourism brings about economic benefits through spending, infrastructure development and investments, destination competitiveness has raised in the last decades interest in the scientific and academic literature. Then, researchers and policymakers are becoming more and more involved in finding the drivers of this phenomenon. However, the complexity and multidimensionality of destination competitiveness make its measurement a challenging task. One of the most powerful tools for measuring multidimensional phenomena is the composite index, and in this paper, a synthetic measure based on a non-compensatory approach for calculating destination attractiveness is proposed. This index, calculated for the Italian regions, is then compared with regional tourism performances, with the aim of assessing destination competitiveness. The results highlight the strength of this approach for the construction of a composite index, and show an original application on Italian regional data.

Keywords

*Composite index, destination competitiveness,
multidimensional phenomena, regional data, tourism
statistics*

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INTRODUCTION

In the international scenario, tourism is definitely one of the most relevant economic activities, also due to the dynamism and the diversification of the sector, which drives job creation and investment for infrastructure endowment (UNWTO, 2020). Before the emergence of COVID-19, the World Tourism Organization had estimated that destinations worldwide received around 1.5 billion arrivals in 2019 (+3.8% compared to 2018), confirming the tenth consecutive year of sustained growth since 2009 (UNWTO, 2020). As the world has faced an unprecedented global health, social and economic crisis

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with the COVID-19 pandemic, travel and tourism industry has been among the most affected sectors (Patrizi and Celardo, 2021).

Starting from these evidences it does not surprise that scientific and academic studies on the performance of the tourism sector are constantly growing (Cracolici and Nijkamp, 2009), in particular those regarding the measurement of the competitiveness of tourist destinations (Gómez-Vega and Picazo-Tadeo, 2019). Since tourism provides direct, indirect and induced economic benefits to destinations through visitor and government spending, infrastructure development and business investments (WTTC, 2020), researchers and policy-makers are particularly interested in finding the key factors that push the competitiveness of the destinations (Hanafiah et al., 2016).

Tourist destinations are highly involved in raising their market share due to the economic and non-economic benefits of competitive advantage; in particular, Mazanec and Ring (2011) have highlighted that a more competitive destination generates higher levels of income, employment, standard of living, well-being and wealth. Despite the growing interest of academics in destination competitiveness topic and the agreement on its valuable benefits, no general consensus has been reached on how tourism competitiveness is defined or on how to measure it (Fernández et al., 2020), mainly because it depends on multiple dimensions that could influence and determine the destination's success (Croes and Kubickova, 2013).

With the aim of comparing the level of tourism competitiveness between different countries, in the year 2007, the World Economic Forum introduced a composite index, known as the Travel and Tourism Competitiveness Index (from 2021, the Travel and Tourism Development Index). The Travel and Tourism Competitiveness Index (TTCI, hereafter) is the most used index for assessing (potential) destination competitiveness, and it is currently being used to measure and compare more than 100 countries worldwide (Kunst and Ivandić, 2021). The measurement of competitiveness is crucial for destinations to advance the performance of tourism, identify direct and indirect impacts, as well as related factors that affect key drivers and policy barriers (Wu et al., 2012). The multidimensional nature of destination competitiveness (Gooroochurn and Sugiyarto, 2005) requires, in order to measure it, the observation of this phenomenon from multiple perspectives and the utilization of suitable statistical approaches that could manage the complexity.

The aim of this paper is twofold: the first objective is to propose an alternative composite index methodology for assessing the drivers of destination competitiveness (i.e., the comparative advantage), explaining the strengths of this approach. Starting from a well-known theoretical framework for the measurement of destination competitiveness, we propose an alternative methodology that, from a statistical point of view, is more robust for the measurement of complex phenomena. The second aim of this paper is to show, through an original application of this index on tourism regional data, the link between the development and the performance level of the Italian regions, to assess the destination competitiveness. To this end, we built a composite index of tourism development for the Italian Regions (hereafter, RTDI), collecting more than 50 indicators from official data sources, each of these available for all the twenty Italian regions.

The paper is structured as follows: Section 1 explains the main issues in measuring multidimensional phenomena from a statistical point of view; Section 2 shows a literature review on destination competitiveness, with a specific focus on its measurement; Section 3 focuses on the methodology used to construct the composite index on destination development; Section 4 describes the data collected and used in this study to assess destination competitiveness of the Italian regions; Section 5 shows the main results of the study and last section draws the main conclusions.

1 MEASURING MULTIDIMENSIONAL PHENOMENA

The scientific community agrees that most socio-economic phenomena are complex, and therefore their measurement and monitoring present different challenges. Complexity often goes hand in hand with

having multiple dimensions, as seen in concepts like competitiveness and infrastructure endowment. Historically, economists tended to view these topics as one-dimensional. However, in recent decades, there has been a global consensus recognizing the multidimensional nature of these phenomena, breaking away from the traditional one-dimensional perspective. The phenomenon of destination competitiveness has become a focal point, drawing attention from stakeholders interested in both theoretical definition and quantitative measurement. Consequently, it is deemed crucial to outline effective steps in handling this complexity, aiming to derive synthetic measures that facilitate the comprehension of a phenomenon that is both fascinating and notoriously elusive to capture.

Shifting from a singular to a multifaceted perspective, broadening and enhancing the analysis scope, marks a significant theoretical advancement with notable advantages for policymaking. However, despite these merits, dealing with multiple dimensions complicates the measurement and evaluation of the phenomenon. While a single indicator could assess a single dimension, a diverse set of indicators is required when dealing with multiple dimensions. This diversity introduces various theoretical and statistical challenges, particularly when attempting comparisons across different times or locations. The primary focus is on determining the most effective approach to represent intricate phenomena and multidimensional realities. Embracing multidimensionality brings several theoretical and methodological challenges absent in the traditional one-dimensional approach (De Muro et al., 2011).

To measure multidimensional phenomena, it's necessary to "combine" various dimensions, treating them as integral components of the phenomenon (Mazziotta and Pareto, 2016). Given the inherent nature of these phenomena, it involves outlining intermediate steps, each of which should be depicted and measured using individual indicators. The statistical and mathematical combination, often referred to as aggregation, of a set of individual indicators representing different dimensions of a phenomenon, can be achieved through specific statistical methodologies, known as composite indicators or composite indexes (Fusco, 2023; OECD, 2008; Saisana and Tarantola, 2002).

The construction of a composite index is a challenging target, full of choices to make and problems to solve, as the theoretical definition of the dimensions, the availability of data, the choice of individual indicators and their treatment, in order to compare (*normalization*) and aggregate them (*weighting and aggregation*). A basic concept to consider regards the relationship among the different steps for constructing composite indices: the theoretical part is not separated from the statistical-methodological one; in fact, the selection of the individual indicators is not independent from the choice of the normalization and aggregation method. The paradigm of work requires that some issues are considered, since they can influence the validity of the results obtained: time and territorial comparisons, compensation among individual indicators, system of weights (Jiménez-Fernández et al., 2022), and robustness of the methodology.

The reduction of dimensions in space is a dangerous task, requiring rules and properties that can guide the arbitrariness of the researcher's choices. Each of these choices has very specific consequences, and in the following paragraphs, they are considered for measuring the multidimensional phenomenon of destination competitiveness of the Italian regions.

2 DESTINATION COMPETITIVENESS: STATE OF THE ART

In recent literature, the investigation and the measurement of destination competitiveness have increasingly attracted interest (Cracolici and Nijkamp, 2009; Dwyer, 2022). A unique and precise explanation of destination competitiveness does not exist (Croes and Kubickova, 2013), but the most widely accepted definition within the academic community is given by Ritchie and Crouch (1993), where it is described as the capability of increasing the number of visitors, while providing a satisfactory experience for tourists, well-being for residents and preserving the natural capital of the territories. This definition has three main elements in common with others in the scientific literature on destination competitiveness

(Fernández et al., 2020). First of all, the notion of competitiveness is strictly related to the ability to increase the attractiveness of the destination and consequently, increasing the number and the expenditure of visitors (Uyar et al., 2023). The second dimension focuses on the capability of giving a satisfactory tourism experience to visitors in comparison with other destinations, while the third and last element of competitiveness refers to the concept of destination sustainability, in terms of preserving residents and natural capital from tourism impacts.

The academic community has been concerned with the implementation of theoretical models that aim to identify, explain and measure the forces that drive destination competitiveness (Novais et al., 2018). Many models have been proposed (e.g., Dwyer and Kim, 2003; Heath, 2003; Ritchie and Crouch, 2003), but the one proposed by Ritchie and Crouch (2003) has been recognized as the most exhaustive framework (Boley and Perdue, 2012). They basically proposed a theoretical model for identifying the success in terms of competitiveness of a tourist destination based on Porter's (1990) *Diamond Model* of competitive and comparative advantages. Comparative advantages in tourism destinations regard the resources/infrastructures that are available – i.e., *resource endowments*. On the other hand, competitive advantages deal with the ability of a destination to make use of the available resources, that is, *resource deployment* (Zehrer et al., 2017). According to the model proposed by Ritchie and Crouch (2003), the competitiveness of a destination is determined by four components: (1) core resources and attractors (e.g., climate, cultural sites, events), which are the primary elements of destination attractiveness for which tourists choose one destination or another (Tang and Rochananond, 1990); (2) supporting factors and resources (e.g. infrastructure, services, accessibility) that allow a destination to develop the tourism industry; (3) destination management activities, essential to improve the attractiveness of core and supporting resources; (4) qualifying and amplifying determinants (e.g., crime rates, fiscal policy), which are a group of elements that could negatively impact on competitiveness.

Destination competitiveness can be measured from a quantitative or a qualitative point of view (Fernández et al., 2020). In the first case, the level of competitiveness is determined through the statistical analysis of data from surveys or official sources, while in the other case, this attribute is inferred from interviews with tourists, agents or experts in the sector. Several empirical studies have applied the models aimed to determine the competitiveness of territories (Crouch, 2011) in order to measure the performances and evaluate the significance of factors influencing the attractiveness of destinations. Most of these studies have measured destination competitiveness from a quantitative point of view, in particular by way of composite indexes (for an extensive review, see Mendola and Volo, 2017).

At the international level, the most important example of a composite index is the Travel and Tourism Competitiveness Index, proposed by the World Economic Forum since 2007 and published in the Travel and Tourism Competitiveness Report. This index serves as a strategic benchmarking tool for policymakers, companies and complementary sectors to advance the future development of the T&T sector by providing insights into the strengths and development areas of each country to enhance the realization of sector potential and growth. As a consequence of the last global shocks (e.g., COVID-19 pandemic), from 2021, the TTCI has been renamed as the Travel and Tourism Development Index, also including a long-term inclusivity, sustainability and resilience of the T&T sector as factors that are taken into consideration for assessing the competitiveness of the destinations (WEF, 2022).

Although the TTCI has been recognized worldwide as a valuable tool for measuring and evaluating (prospective) destination competitiveness, it has also raised a lot of criticisms, especially regarding methodological issues (Croes and Kubickova, 2013; Gómez-Vega and Picazo-Tadeo, 2019; Pulido-Fernández and Rodríguez-Díaz, 2016), which mainly regard: (1) countries are equally treated, and no differences in terms of the level of development are taken into consideration; (2) both quantitative and qualitative variables are integrated into a single composite index for the calculation of the TTCI; (3) it is not clear how to determine the weights used in the aggregation process of the individual indicators

so that many researchers have tried different alternatives for weighting the TTCI data, as for example factor analysis (Mazanec and Ring, 2011).

From a statistical point of view, in addition to these criticisms, the normalization and the aggregation processes for constructing the TTCI also present some weaknesses. The normalization method adopted for the construction of the TTCI is widely used in literature because it allows comparisons over time. However, since the TTCI does not take into consideration time comparisons, it is possible to benefit by a method that eliminates more variability from the data, so that all the individual indicators have the same implicit weight. In fact, in the current version of the TTCI, from a statistical point of view each individual indicator, if it is not appropriately standardized, assumes importance in proportion to its variability. This is not advisable because if an individual indicator has high variability, it does not imply that it should be of high importance in the model. Therefore, with the current methodology, in the construction of the TTCI the individual indicator with the highest variability weighs more than the indicator with lower variability even if, from a theoretical point of view, it must not have greater importance. The range of the standardization method (from 1 to 7) seems to be very short to analyse properly the distances between countries; in fact, there are many countries with the same score, and it is not easy to understand the differences when the variability is so flattened (this, as described below, is also reflected in the aggregation phase). A relevant problem regarding the absence of a reference value is added to this. Indeed, the average of the distributions of the standardized values is not 4 (considering the 1-to-7 scale). Therefore, the values must be read exclusively as pure numbers, without a term of comparison or a benchmark: this evidence limits the analysis of the results and any political decision. The biggest criticism concerns the aggregation method because the use of the arithmetic mean is very dangerous when the components of the phenomenon are not replaceable or have different importance from the point of view of the theoretical framework. The TTCI envisages the arithmetic mean as the one and only method of synthesis at all levels of the composition process. This choice determines the perfect compensation of the elementary indicators, pillars, sub-indices and overall index.

Statistical, economic and social literature agree that the arithmetic mean cannot be used alone to measure multidimensional phenomena, especially in the case in which it is necessary to adopt a formative measurement model (Diamantopoulos et al., 2008). The case of tourism competitiveness is no exception. From this point of view, the TTCI does not take into consideration the issue of aggregation and weighting of the components that represent the complexity of the phenomenon. Trying to approach the problem from a statistical point of view, if the individual indicators have the same weight, then using a function such as the arithmetic mean is wrong because there is a compensation between dimensions of equal importance. From this evidence, it can be understood that the TTCI produces distorted results with respect to the phenomenon to be measured. For this reason, in this paper a different statistical method for the construction of the composite index is proposed.

3 METHODOLOGY AND PARADIGM OF WORK

It would be indispensable to think of a synthesis methodology in which, in the normalization phase, the implicit variability is eliminated, and then, in the aggregation phase, a non-compensatory function is used. The literature offers various aggregation methods, all with their advantages and drawbacks. As in the TTCI case, additive methods are prevalent, but they imply conditions which are often undesirable or challenging to fulfil. Indeed, a fundamental issue concerning the aggregation is the degree of compensability or substitutability of the individual indicators.

The Mazziotta-Pareto Index (MPI) is a composite index for summarizing a set of indicators that are assumed to be not fully substitutable. The MPI is designed in order to satisfy the following properties: (1) normalization of the indicators by a specific criterion that eliminates both the unit of measurement

and the “variability effect”, (2) synthesis independent of an “ideal unit”, since a set of “optimal values” is arbitrary, non-univocal and can vary with time, (3) simplicity of computation and (4) ease of interpretation.

Let $\mathbf{X}=\{x_{ij}\}$ be the matrix with n rows (Italian regions) and m columns (tourism indicators), and let M_{x_j} and S_{x_j} denote the mean and the standard deviation of the j -th indicator:

$$M_{x_j} = \frac{\sum_{i=1}^n x_{ij}}{n}; \quad S_{x_j} = \frac{\sum_{i=1}^n x_{ij}}{n}. \tag{1}$$

The standardized matrix $\mathbf{Z}=\{z_{ij}\}$ is defined as follows:

$$z_{ij} = 100 \pm \frac{(x_{ij} - M_{x_j})}{S_{x_j}} 10, \tag{2}$$

where: the sign \pm depends on the relation of the j -th indicators with the phenomenon to be measured (+ if the individual indicator represents a dimension considered positive, and – if it represents a dimension considered negative).

Let cv_i be the coefficient of variation for the i -th unit:

$$cv_i = \frac{S_{z_i}}{M_{z_i}}, \tag{3}$$

where:

$$M_{z_i} = \frac{\sum_{j=1}^m z_{ij}}{m}; \quad S_{z_i} = \sqrt{\frac{\sum_{j=1}^m (z_{ij} - M_{z_i})^2}{m}}. \tag{4}$$

Then, the generalized form² of MPI is given by:

$$MPI_i^{+/-} = M_{z_i} (1 \pm cv_i^2) = M_{z_i} \pm S_{z_i} cv_i, \tag{5}$$

where the sign of the penalty (the product $S_{z_i} cv_i$) depends on the kind of phenomenon to be measured and the direction of the individual indicators.³

The MPI is based on a non-linear function, which, starting from the arithmetic mean of the standardized indicators, introduces a penalty for the units with unbalanced values of the indicators. The objective is to reward the units that, mean being equal, have a greater balance among the values of the indicators (De Muro et al., 2011). Therefore, the MPI decomposes the score of each unit in two parts: mean level and penalty. In the phase of standardization, each individual indicator is transformed in a z -score with mean

² It is a generalized form since it includes “two indices in one”.

³ For a simulated example for computing the composite index (MPI), see De Muro, Mazziotta and Pareto (2011).

equal to 100 and standard error equal to 10 ($mean = 100$ and $s.e. = 10$); the standardized values will be in the range 70–130. This procedure allows to deparate the indicators both from the unit of measure and from the variability, and it does not require the definition of a target values (ideal unit) because it replaces the vector with the average of values. In this way, it is easy to identify the units with a level of the phenomenon above average (values greater than 100) and the units with a level below the average (values less than 100). In the phase of aggregation, the function adopted (arithmetic mean of standardized values) is “corrected” by a penalty coefficient that depends, for each unit, on the variability of the indicators compared to the average value (horizontal variability). This variability, measured by the coefficient of variation (CV), allows to penalize the score of the units that, with the same arithmetic average, have a higher imbalance between the values of the indicators. The penalty can be added or subtracted, depending on the type of the studied phenomenon: positive (e.g., development) or negative (e.g., poverty) (Mazziotta and Pareto, 2016). This method implicitly assigns to all indicators the same weight, eliminating the variability. It is applicable to any phenomenon, changing the sign of the penalty. The index can be decomposed into two parts: the average effect (*compensatory*) and the penalty effect (*imbalance*). It is possible to make only relative comparisons of the values of the units, with respect to the average, over time.

In the literature, the comparison between different composite indexes methodology in a formative approach (Diamantopoulos et al., 2008) has shown that the MPI, due to the standardization approach (z -score) and the aggregation function (*penalized arithmetic mean*), guarantees a high level of robustness (Mazziotta et al., 2010; Mazziotta and Pareto, 2016). On the other hand, the use of Principal Component Analysis (PCA) or other factor analysis as synthesis methods of multidimensional phenomena in a formative approach (Lafuente et al., 2022) presents many statistical and theoretical problems.

The MPI allows to overcome the problems of the TTCI methodology and guarantees, on the one hand, individual indicators purified from the implicit weight of the variability, and, on the other hand, a non-compensatory aggregation function without the defects of the geometric mean. The weighting system provides that each indicator has equal theoretical importance. As described below, in the case study, a composite index for each of the 13 pillars is calculated, then a composite index of the composites is calculated to determine the 4 sub-indexes and again a composite index of the composites for the final index. In all steps of this process, MPI is used (when the composite index is calculated starting from other composite indices, then only the aggregation phase is applied, i.e. a new standardization is not calculated as all the values are already expressed in the same unit of measurement).

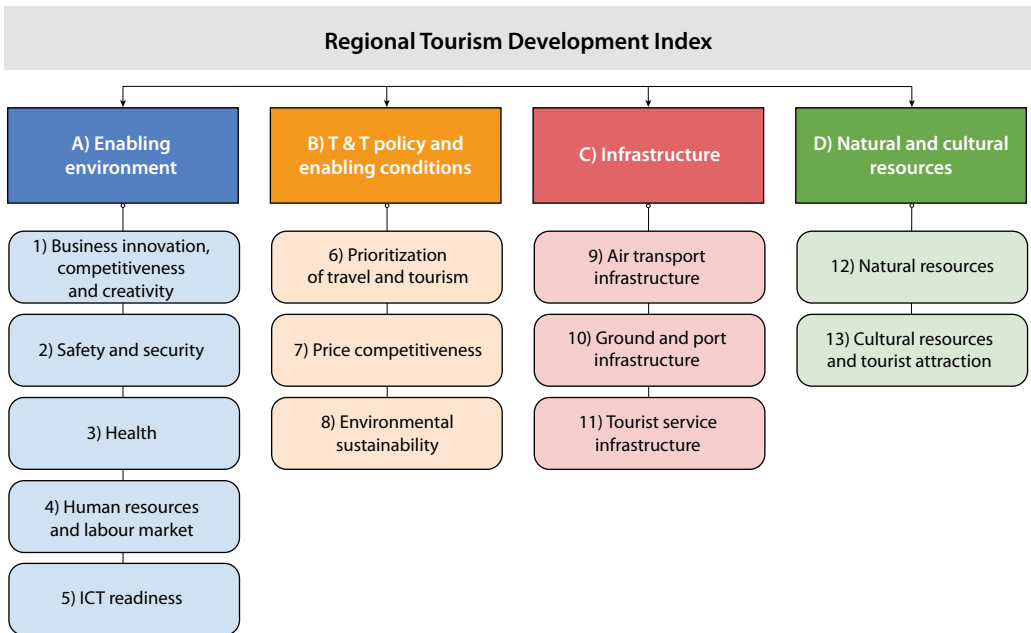
After the calculation of the composite indexes, we implemented an influence analysis in order to identify the sub-indexes that mostly determine the differences among regions. Influence analysis quantifies the weight of each sub-indexes in the calculation of the composite (Mazziotta et al., 2010). Given K indexes, K replications are performed, excluding each time a different sub-index and calculating the values of the composite indicator based on the remaining $K-1$ indexes. For each replication, the rankings of the regions are obtained, and for each one, the absolute differences of rank between the position in the original rank and the position in the ranking for the $K-1$ indicators are calculated. Finally, the arithmetic mean of absolute rank differences is calculated: the sub-index with the lowest mean value represents the dimension that influences less the composite, and then the phenomenon that less determines differences among regions.

In order to measure the destination development of Italian regions through the RTDI, we used the theoretical framework developed by the World Economic Forum for the construction of the Travel and Tourism Competitiveness Index.

However, since the measurement is focused on regions and not on countries in this study, and considering the specificities of Italy, we have adapted the framework of the index as shown in Figure 1. Comparing the proposed index to the original framework, the main changes implemented in the structure of the index are:

1. Concerning the first pillar of the first sub-index (A.1), instead of measuring the business environment just in terms of capacity development of a policy environment conducive for companies to do business, we included in this pillar also measures related to the capacity of enterprises to be innovative and creative;
2. Concerning the third pillar of the first sub-index (A.3), since the Italian regions show no differences in terms of hygiene regulations and practices, in this pillar we take into account only indicators related to health;
3. Concerning the second sub-index (B), we excluded the pillar *International Openness* related to openness and travel facilitation since, in this study, we compare regions of the same country where there are no restrictions in terms of mobility across areas;
4. Concerning the last pillar of the fourth sub-index (D.2), we modified the domains excluding business travel indicators, and including measures related to tourist attractions. The rationale behind the choice of excluding business travel domain lies in the fact that at the regional level, in the Italian context, there are no available measures related to the number of association meetings taking place, and there are neither available other measures related to associations meetings facilitations or premises. However, we included in this pillar also measures related to tourist attractions since they could represent a region catalyst for tourist arrivals, as it is for a museum or a monument.

Figure 1 Theoretical framework of the regional tourism development index (RTDI)



Source: Own elaboration

4 DATA AND RESULTS

In previous paragraph, we proposed an alternative approach for the calculation of a composite index on destination development in comparison to the TTCI methodology. As previously reported, the TTCI has been the target of significant criticism from a methodological point of view (Rodríguez-Díaz and Pulido-Fernández, 2021), while the theoretical framework is widely supported by the scientific community.

In this section, we show the application of MPI methodology to regional tourism data to assess the Italian destinations attractiveness. Other studies have investigated destination competitiveness of Italy, in relation to municipalities (Grassini et al., 2023), small versus medium destinations (Goffi and Cucculelli, 2019) or Southern destinations (Cracolici and Nijkamp, 2009), among others. In this case study, we assess the endowments of all the Italian regions, adapting the theoretical framework of the TTCI.

In order to measure the destination development of the Italian regions, we collected 54 individual indicators (Appendix – Table A1). Data refer to the latest available year in the time series for each indicator,⁴ where all the indicators have been updated in October 2023. All the indicators selected for the analysis have been updated, referring to the latest available year in the time series at the time of the study. Some of the indicators used for the index calculation are updated annually, while others are updated every two, three, or five years.⁵ The intermittent updating of these indicators is due to the fact that they refer to phenomena that change not significantly over time, so an annual update of this data is not considered worthwhile. The majority of the indicators have as the reference year 2021 or 2022 (these are the indicators with an annual update), while only for data that do not present an annual update, we took a previous year (Appendix – Table A1). Considering that, we assume the reference year of the composite index is 2022.

The selection of the indicators was made taking into consideration i) the theoretical framework of the composite index, ii) the data already used by the WEF for the construction of the TTCI, and iii) the data availability in Italy at the regional level.⁶

After a preliminary descriptive analysis of the individual indicators, we constructed the composite index on the regional touristic development of the Italian regions. Figure 2 shows the map of Italy, where regions are filled with colour based on the composite index values (Appendix – Table A2); as shown in the legend, the darker green areas (Lombardy, Tuscany and Veneto) are those regions showing the highest values of the composite index and, therefore, present advantages in terms of travel and tourism industry. On the other hand, the darker orange areas (Calabria, Molise and Campania) are the regions with the lowest level of endowments.

Overall, it can be observed that there is not a lot of variability among regions since between the worst performers (Calabria) and the best performer (Veneto), the difference in terms of the value of the composite index is less than 10 (93.98 and 102.82, respectively).⁷ Another interesting aspect of the map is the value of the composite index, which strictly reflects the classical geographical categorization

⁴ The cross-section nature of this study does not allow direct temporal comparisons, since it was agreed to not work with time series, due to the static nature of the measured dimensions. In fact, on the indicators collected for the construction of the composite, we observed very little changes over time, so we decided to work with the latest year available for each indicator. However, as future improvements of this study, the analysis could be re-implemented after a period of time (5 years, for instance), to assess if variations in ranks occur.

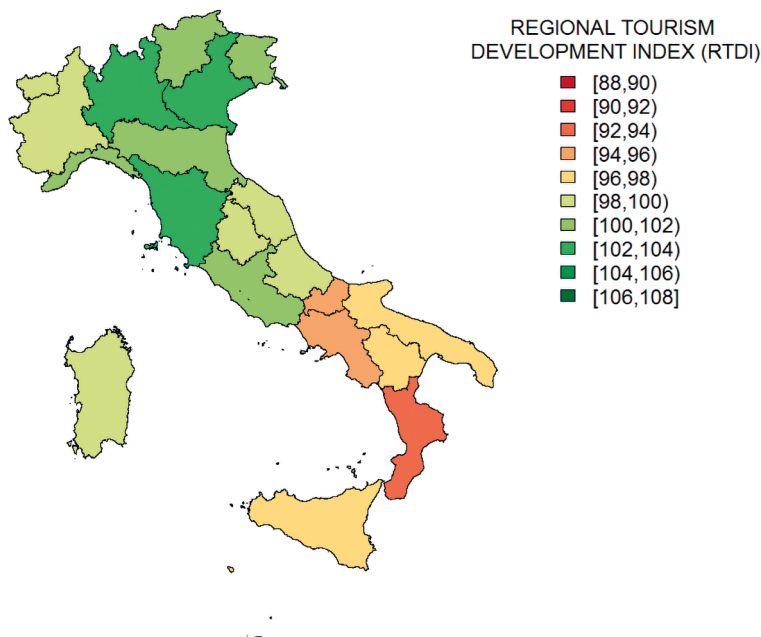
⁵ For instance, the forest area index (FAO) is updated every 5 years, so at the time of this study the latest data available referred to 2020.

⁶ The availability of regional data could represent a limitation for the analysis, since many indicators are only produced at national level. On one side, calculating a regional index allows a better understanding of the internal differences in a Country; on the other side, the selection of the indicators is limited to those that are disaggregated by region, reducing the set of information available for the analysis.

⁷ In terms of variability of the composite, the coefficient of variation calculated on the regional distribution of the RTDI is equal to 2.5%. This measure of variability was also calculated on the 13 pillars and on the four sub-indexes, to assess which domains present the highest level of heterogeneity at territorial level. Considering the 13 pillars, the domains that show significant disparities at regional level are pillar A4 (*Human resources and labour market*), pillar A5 (*ICT readiness*), pillar A6 (*Prioritization of Travel and Tourism*) and pillar C9 (*Air Transport Infrastructure*), having a coefficient of variation of around 8%. Considering the four sub-indexes, the dimension presenting the highest variability at territorial level is the one that captures the general conditions necessary for operating in a region (*Enabling environment*), having a coefficient of variation equal to 5.4%, while for the dimension D (*Natural and Cultural Resources*) the regional variability is the lowest (CV = 2.4%).

of the Italian regions. In fact, all the regions coloured orange are in the south of Italy, while all the regions with a higher score on the composite index are in the middle and in the north of Italy. This evidence strictly reflects an existing gap between the macro areas of Italy, both from economic and social points of view. The results of this analysis confirm that also in terms of tourism attractiveness there is a clear gap between these areas, which cannot be solely explained by the higher or lower presence of some touristic endowments in a specific area. For example, the southern regions have many artistic and natural resources. Considering the UNESCO heritage (unique, not shared), Sicily is the region with the highest number (7), along with Tuscany; Campania has 5, more than Lombardy (4). This evidence might suggest that it is not only the “natural” endowment of a territory that makes the difference in terms of attractiveness (museums, archaeological finds, landscapes, etc.) but also the services and infrastructures offered to tourists.

Figure 2 Regional Tourism Development Index (RTDI)



Source: Own elaboration

Going into detail, there are many different factors that could explain the gaps among the different Italian regions. A way to better understand the drivers of the inequalities is to look at the different characteristics of these areas within the four sub-indexes composing the final composite index (Figure 3).

Figure 3 shows the map of Italy where the regions are coloured considering the characteristics of the four sub-dimensions of destination development. Concerning dimensions A and C (*Enabling environment and Infrastructure*), it is possible to observe the presence of more variability among Italian regions⁸ since the distances between the worst and the best performers in these two dimensions are much higher than the ranges observed in the composite indexes calculated for dimensions B and D (*T&T policy and enabling conditions and Natural and cultural resources*).

⁸ See the Appendix.

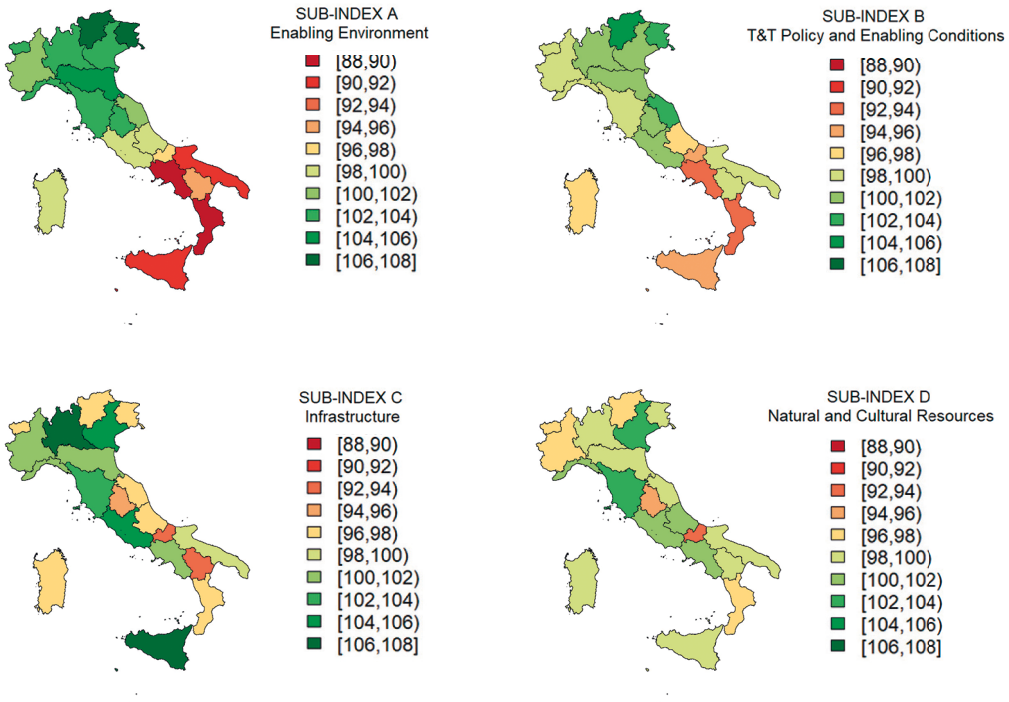
Concerning dimension A – *Enabling environment* – the map shows, again, a strong disparity between the North and the South in terms of endowments. The composite index shows that the Campania and Calabria regions are the least endowed, while Trentino-South Tyrol and Friuli-Venezia Giulia regions are the most ones in this area.

Concerning the second dimension – *T&T policy and enabling conditions* – the map shows a lower level of variability among regions in comparison to the previous sub-index. In fact, the composite index for the sub-index B ranges between 93 and 105. Again, there is a polarization of the scores of the composite index reflecting the disparities among the South and the North. In fact, the most endowed region (Trentino-South Tyrol region) is located in the northern area, while the least are almost all located in the South. As previously mentioned, Trentino-South Tyrol is, also in the case of *T&T policy and enabling conditions* dimensions, the region that scores highest, followed by Friuli-Venezia Giulia and Marche. On the other hand, the least developed are, as it was for the sub-index A, Calabria and Campania, followed by Sicily and Molise.

Moving to the third sub-index, *Infrastructure*, the figure shows a complete change in the regions’ ranking compared to the previous sub-indexes. In fact, most endowed regions are located in both the North and the South, but the same occurs with least endowed regions. The regions showing the highest scores for this dimension are Sicily and Lombardy, followed by the Lazio and Veneto regions. Looking at the worst performers, the regions that score lowest are Molise and Basilicata, followed by the Umbria region.

The fourth sub-index (*Natural and Cultural Resources*) calculated for the Italian regions shows a lower variability among territories – in comparison with the previous sub-index, since the composite index ranges from 93 to 104. The least endowed region is Molise, while the most endowed are Tuscany and Veneto.

Figure 3 Sub-indexes of regional touristic development



Source: Own elaboration

In terms of association between the RTDI and the four sub-indexes, while a high correlation occurs between RTDI and sub-index A (*Enabling environment*) and sub-index B (*T&T policy and enabling conditions*), we observed a weaker correlation between the RTDI and the sub-index C (*Infrastructure*) and sub-index D (*Natural and cultural resources*). These results show that, while for general conditions necessary for operating and policies or strategic aspects that impact the T&T industry, the relationship with the total potential attractiveness is linear (highest the level of these services/conditions, higher the level of the total potential attractiveness of the region), in terms of infrastructure and/or natural/cultural resources, this link is not symmetric, meaning that those regions performing better on this two dimension, are not automatically those with the highest scores in terms of total potential attractiveness.

We then replicated the calculation of the RTDI using the original TCI index methodology (normalization and aggregation) in order to compare the results, observe and rank the regions for both the indexes and see if and how the new methodology affects the ranking obtained. The correlation between the two indexes is very high (*Pearson correlation coefficient* = 0.99), consisting of few differences in terms of shifts in rankings. In particular, the bottom parts of the two rankings are equivalent, while the shifts observed are exclusively in the top positions of the rankings. Differently from the RTDI calculated with the new methodology, the other index shows in the second position the Lombardy region (third position for the RTDI), while the third best performer is the Trentino-Alto Adige region (seventh position for the RTDI). Even if there are no significant changes from one ranking to another, there are two important factors that make the RTDI easier to interpret. The first point regards the range of the index: the RTDI has a range of almost 9 points, while the other index has a range of 1.3, which does not allow us to clearly observe the distances between regions. The second issue regards the “reference” score. The MPI methodology is based on a range of 70–130, where 100 represents the average value, so then it is possible to compare each score of the index to see if that region is above or below the average. The TCI methodology does not allow for this type of assessment, so by looking at the ranking, it is only possible to identify the best and the worst performers.

After the calculation of the RTDI, we implemented an influence analysis in order to identify the sub-indexes that mostly determined the differences among regions. Then, we calculated the arithmetic mean of absolute rank differences: the sub-index with the lowest mean value represents the dimension that less influences the composite, and then that less determines differences among regions.

The influence analysis revealed that, overall, the first dimension – *Enabling environment* – mostly contributed to regional differences in tourism development, determining an average shift in the ranking of 2.1 (Table 1). On the other hand, *Natural and cultural resources* dimension (sub-index D) has no substantial impact on regional disparities since the average shift in ranking is equal to 1.5, indicating that this dimension has less influence on the composite index.

Table 1 Results of the influence analysis

Sub-index	Influence (average shift in the ranking)
A – <i>Enabling environment</i>	2.1
B – <i>T&T policy and enabling conditions</i>	1.6
C – <i>Infrastructure</i>	1.9
D – <i>Natural and cultural resources</i>	1.5

Source: Own elaboration

In the last step of this analysis, we related the composite index to some outcome indicators in order to identify the regions associated with the highest performances in tourism. There are several studies that correlate the development of the destination touristic industry with outcome indicators – such as for example, tourist satisfaction, competitiveness, tourist arrivals, and economic indicators from

the Tourism Satellite Account (Hanafiah and Zulkifly, 2019). In particular, in this analysis, we compared the RTDI with four performance indicators: accommodation and food service sector value added, tourist arrivals, overnight stays in tourist accommodations and tourism expenditure. The objective is to understand, in the case of Italy, if a higher development of the destination is connected to a stronger effective capacity to attract tourists and generate additional value.

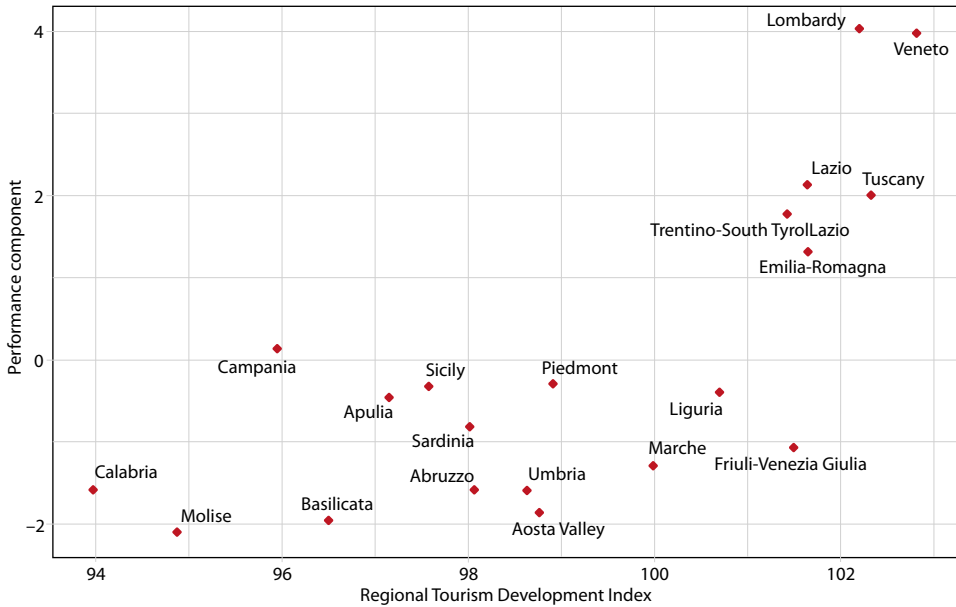
Due to the high correlation between the four performance indicators,⁹ we implemented a Principal Component Analysis, keeping the first component as a synthesis of the four original dimensions.¹⁰ We regarded the first component as a proxy of the destination competitiveness and we analysed the correlation between this component and the Regional Tourism Development Index, in order to assess for the 20 Italian regions the correspondence between their potential attractiveness and their results in the touristic sector.

The results are shown in the scatterplot (Figure 4). The scatterplot displays the link between the first component of the PCA and the RTDI. As clearly visible in the graph, between these two dimensions, there is a high positive correlation (*Pearson correlation coefficient* = 0.73), meaning that those destinations that are more advanced and developed in terms of infrastructures, business environment and natural/cultural resources, are also (on average) more likely to attract tourists, and then more competitive. It is important to note from the scatterplot that there are also Italian regions for which this relationship is not fully assumed. For instance, looking at Friuli-Venezia Giulia, we notice that even if the value of the composite index is relatively high, the value of the performance component is not as high as expected. A similar trend is observed for other destinations, such as Marche and Liguria. Therefore, these destinations show a failure in their resource deployment because the market performance is not fully achieved. This result draws attention to the fact that it is not sufficient for destinations to have a comparative advantage: in fact, territories have to put in place policies and specific interventions in order to concretely attract tourists. The potential of these regions, in terms of their capacity to attract tourists, is definitely very high, and should be better exploited through targeted interventions and systematic public policies. The opposite situation is observed for the Campania region. In this case, even if the score for the RTDI is low, showing difficulty for the region to have a comparative advantage in terms of resources available, the market performance is relatively high. This example brings to the attention that even if the availability of resources is a driver of competitiveness, there are some cases in which other unobserved factors play a crucial role.

A more in-depth analysis allows us to better understand the relationship between the destinations' market performances and the four sub-components of the composite index. In fact, as the performance component and the RTDI are significantly correlated, the third sub-dimension of the index – *Infrastructure* – is also highly correlated with the performance measure (*Pearson correlation coefficient* = 0.78). For the other three sub-dimensions, the positive association between input and outcome is much less strong. In fact, the second and the fourth sub-dimensions – *T&T Policy and Enabling Conditions* and *Natural and Cultural Resources* – show a moderate correlation (*Pearson correlation coefficient* = 0.43 and 0.53, respectively), while the first sub-dimension – *Enabling Environment* – is not significantly associated with the performance synthetic factor (*Pearson correlation coefficient* = 0.29). From these results, we deduce that, in the Italian context, the availability of high-quality physical infrastructure and tourism services is the main driver of destination competitiveness, followed by the natural and cultural resources – i.e., *reasons to travel*. Except for Trentino-South Tyrol, where high market performances are associated with a relatively low infrastructure development, none of the destinations showing a competitive advantage in terms of performance has, at the same time, a low score for this sub-index.

⁹ Pearson correlation coefficients range between 0.79 (added value and overnight stays indicators) and 0.98 (arrivals and overnight stays indicators).

¹⁰ The variance explained by the first factor of the Principal Component Analysis is equal to 90.9%.

Figure 4 Scatterplot of the RTDI and the performance component

Source: Own elaboration

CONCLUSIONS

Italy, people of poets, artists, heroes, saints, thinkers, scientists, navigators and transmigrators. Certainly, each of Italy's epochs left a tangible mark from an artistic (and not only) point of view.

In some periods, Italy has been one of the greatest centres of political, cultural and civil development. It is not by chance that Italy is one of the most visited countries in the world. It follows that Italy must also consider tourism as a fundamental engine of its economy. Italy is also well-known for having strong internal variability from an economic and social point of view. These conspicuous differences, rooted in the country's history, have attracted the attention of social, economic and political scientists (e.g. Banfield, 1958; Putnam et al., 1993; Solivetti, 2020). Italy is said to be the country of municipalities: many, small and dissimilar. In a nutshell, the North is more developed than the South: could internal differences also be visible in the tourism sector? Our research questions are focused, on the one hand, on interpreting these internal differences through the analysis of tourism attractiveness and, on the other, on finding a synthetic measure for quantifying it from a statistical point of view.

We adopted the theoretical framework of the TTTCI, because we considered it appropriate for the case of the Italian regions. The MPI has been calculated because it provides greater guarantees from a mathematical point of view. The new composite index, the Regional Tourism Development Index (RTDI), provides interesting results on the Italian regions, and it can be used as an analysis tool to understand the territorial features and plan intervention policies.

The territorial differences along the "boot" are those of Italy's historical problems: it is said that Italy is a country with two speeds. Certainly, those who live in the North have better resources than those who live in the South, from many points of view. Tourism is not an exception. The tourist competitiveness of a region does not depend only on the artistic or natural beauties it possesses; some tourist sites in the South have equal or greater value than some in the North. So why does the RTDI show Italy split in two?

The analyses presented in the paper show that regional tourism development depends on the territorial context, that is, the social and economic development capacity of an area. The territorial context depends on the infrastructural endowment, citizens' education, services offered, crime rate, civic sense, social capital, politics, local administration and much more. To this end, the TTCI and the proposed composite index are measures of determinants – meaning, potential conditions of competitiveness of territory – and not performance-based indicators. Four performance indicators have been compared to the RTDI in order to assess if a higher level of potential touristic attractiveness of a region is linked to higher tourism competitiveness. The results showed that, on average, this association is confirmed since the correlation between the RTDI and tourism performance is close. However, as we showed in the previous paragraph, there are some specific cases where a high level of potential attractiveness is associated with bad performances in terms of capacity to attract tourists (see, for example, Marche, Liguria and Friuli-Venezia Giulia regions). These results clear the way to a further discussion on how to improve the destinations' competitiveness.

The results of the RTDI, from this point of view, are very clear: the most beautiful tourist sites in the world, if not included within an adequate territorial context, could be unable to attract tourists. It could be called the “hidden city paradox”. Suppose that an ancient city is brought to light again after thousands of years, and this discovery is such an extraordinary event that it attracts interest from all over the world. However, if this wonderful city is not reachable by any means of transport, if the place is not equipped with adequate accommodation facilities, if safety and public order are not respected, and if the local government does not understand the importance of this discovery, then digging the city up would not generate significant advantages as to tourism.

The RTDI seems to well represent tourism potential attractiveness by showing the strengths and weaknesses of the regions. There are regions that are not competitive – e.g., Basilicata, Calabria, Molise – because they do not have an offer comparable with other areas of the country from an artistic point of view. Nevertheless, Campania too shows a low level of development, but it is attractive for tourists since the score of the performance component is relatively high. Lazio, Tuscany and Veneto have a high level of competitiveness because the cities of Rome, Florence and Venice guarantee high performances. Lombardy is the engine of Italy, as Milan is the Country's business capital, and some of Lombardy's provincial capitals are among the most developed areas in Europe from many points of view. Friuli-Venezia-Giulia, Liguria and Marche have a good level of touristic development, but they need to further exploit marketing tools in order to better propose their wonders. Trentino-South Tyrol, over the years, has assumed the role of the world capital of the mountains, thanks to the extraordinary Dolomites inserted in a territorial context of absolute efficiency. Abruzzo, Piedmont, Apulia, Sardinia and Aosta Valley have some excellent endowments, but their level of total potential attractiveness is lower than the national average: the composite indices of the sub-dimensions suggest that these regions need large investments to develop the different components of the territorial context.

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APPENDIX

Table A1 Individual indicators, by pillar, sub-index, reference year and data source

ENABLING ENVIRONMENT (A)		
Business innovation, competitiveness and creativity (A1)	Enterprises net entry rate (A1.1)	ISTAT – Infocamere Movimprese (2021)
	Patent applications (A1.2)	Ocse – Database Regpat (2019)
	Innovative enterprises (A1.3)	ISTAT – Cis (2021)
	Enterprises with web site (A1.4)	ISTAT (2022)
	Labour productivity of tourism activities (A1.5)	ISTAT (2019)
	Employed persons in creative industries (A1.6)	ISTAT (2021)
Safety and security (A2)	Pickpocketing (A2.1)	Ministry of Home Affair (2022)
	Robbery (A2.2)	Ministry of Home Affair (2022)
	Corruption (A2.3)	ISTAT (2016)
Health (A3)	Hospital beds (A3.1)	Ministry of Health (2019)
	Physicians (A3.2)	IQVIA ITALIA (2020)
	Nurses and midwives (A3.3)	Co.Ge.A.P.S. (2020)
Human resources and labour market (A4)	Tertiary education (A4.1)	ISTAT (2022)
	NEET (A4.2)	ISTAT (2022)
	Lifelong learning (A4.3)	ISTAT (2022)
	Hourly earnings (A4.4)	ISTAT (2021)
	Gender employment gap (A4.5)	ISTAT (2021)
ICT readiness (A5)	Electric power distribution (A5.1)	ISTAT – Arera (2020)
	Digital skills (A5.2)	ISTAT (2020)
	Broadband connection (A5.3)	ISTAT (2022)

Table A1

continuation

T&T POLICY AND ENABLING CONDITIONS (B)		
Prioritization of travel and tourism (B6)	Final consumption expenditure – recreation, culture and religion (B6.1)	ISTAT (2019)
	Destination appeal (B6.2)	Demoskopika (2020)
Price competitiveness (B7)	Consumer prices (B7.1)	ISTAT (2021)
	Energy consumer prices (B7.2)	ISTAT (2021)
	Transport consumer prices (B7.3)	ISTAT (2021)
	Accommodation consumer prices (B7.4)	ISTAT (2021)
	Fuel price (B7.5)	Ministry of Economic Development (2021)
Environmental sustainability (B8)	Urban sewage treatment (B8.1)	ISTAT (2020)
	PM10 (B8.2)	ISPRA (2021)
	Separate collection of municipal waste (B8.3)	ISTAT (2021)
	Renewable energy (B8.4)	TERNA (2020)
	Illegal building rate (B8.5)	CRESME (2021)
	Environmental certification (B8.6)	ISTAT (2021)
	Forest area index (B8.7)	FAO (2020)
INFRASTRUCTURE (C)		
Air transport infrastructure (C9)	Airports (C9.1)	ENAC (2022)
	Passenger traffic (C9.2)	Assaeroporti (2019)
Ground and port infrastructure (C10)	Road density (C10.1)	Ministry of Infrastructure and Transport (2014)
	Highway density (C10.2)	ANAS (2014)
	Railway (C10.3)	Ministry of Infrastructure and Transport (2018)
	Seaports (C10.4)	Porti D'Italia (2022)
Tourist service infrastructure (C11)	Hotel rooms (C11.1)	ISTAT (2022)
	Collective accommodation establishments (C11.2)	ISTAT (2022)
	Quality of tourism infrastructure (C11.3)	Demoskopika (2020)
	ATM (C11.4)	Banca D'Italia (2021)
	Seat-Km of public transport networks (C11.5)	ISTAT (2021)
NATURAL AND CULTURAL RESOURCES (D)		
Natural resources (D12)	Urban green areas (D12.1)	ISTAT (2021)
	Protected natural areas (D12.2)	Ministry of Environment (2021)
	Marine areas (D12.3)	Ministry of Environment (2022)
	Coastal bathing waters (D12.4)	Ministry of Health (2019)
Cultural resources and tourist attractions (D13)	Museums and similar institutions (D13.1)	ISTAT (2022)
	Entertainments (D13.2)	SIAE (2021)
	Sports stadiums (D13.3)	Our elaboration (2022)
	UNESCO World Heritage cultural sites (D13.4)	UNESCO (2022)
	Ski resorts (D13.5)	Our elaboration (2022)

Note: Data refer to the latest available year in time series in October 2023.

Source: Own elaboration

Table A2 Values of the composite indexes, by region

Italian regions	Sub-index A: Enabling environment	Sub-index B: T&T policy and enabling conditions	Sub-index C: Infrastructure	Sub-index D: Natural and cultural resources	Regional Tourism Development Index (RTDI)
Veneto	102.69	101.35	105.27	102.03	102.82
Tuscany	102.16	99.95	103.37	103.82	102.3
Lombardy	102.88	100.79	106.32	99.06	102.19
Emilia-Romagna	104.74	101.48	101.24	99.3	101.65
Lazio	98.23	101.11	105.64	101.87	101.64
Friuli-Venezia Giulia	107.32	102.02	97.93	99.15	101.48
Trentino-South Tyrol	106.44	105.14	96.87	97.9	101.41
Liguria	102.32	98.89	101.32	100.3	100.69
Marche	101.38	102.75	96.36	99.63	99.97
Piedmont	100.13	98.34	100.06	97.12	98.9
Aosta Valley	103.28	99.02	96.97	96.08	98.76
Umbria	103.64	101.57	94.81	95.13	98.63
Abruzzo	98.34	96.46	96.64	100.96	98.06
Sardinia	99.66	97.51	96.46	98.51	98.02
Sicily	90.32	95.26	106.32	99.78	97.56
Apulia	91.85	99.3	98.13	99.73	97.15
Basilicata	95.33	98.24	92.84	99.88	96.5
Campania	88.71	93.67	100.78	101.8	95.94
Molise	97.16	95.98	93.02	93.44	94.87
Calabria	88.85	93.18	97.97	96.43	93.98
Coefficient of variation	5.40%	3%	4%	2.40%	2.50%

Source: Own elaboration

The Dynamic Nexus between Macroeconomic Factors and Income Inequality: Evidence from Lower-Middle-Income Countries

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Abstract

Income inequality has been a persistent challenge for policymakers worldwide, especially in developing economies. This study aims to explore the dynamics of income inequality in lower-middle-income economies by analyzing the long-run impact of critical macroeconomic factors. Utilizing annual panel data for 18 lower-middle-income countries from 1996 to 2018, the study employs the Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS). Furthermore, the Pooled Mean Group (PMG) estimator is utilized to validate coefficient estimation. The findings suggest a significant nonlinear linkage between economic growth and income inequality and confirm the Kuznets Curve Hypothesis (KCH) in the selected panel. The findings also substantiate significant long-run positive effects of inflation, trade, and unemployment on income inequality. However, the long-run impact of gross capital formation (GCF) is insignificant. The insights gained from this study could inform policymaking to foster inclusive economic growth and reduce income disparities within lower-middle-income economies.

Keywords

Income inequality, macroeconomic factors, lower-middle-income countries, dynamic panel models

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INTRODUCTION

Income inequality is an indicator that quantifies the degree to which income is evenly distributed among individuals within a given population. A more uneven income distribution indicates higher income

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inequality, while a more even distribution reflects lower income inequality (OECD, 2023). Income inequality poses significant global challenges that hinder development across developed and developing regions. Addressing income inequality is important for promoting social justice and sustainable economic development. As such, it remains a critical concern on the agenda of international organizations and policymakers dedicated to promoting inclusive and equitable development. For instance, the United Nations (UN) has made addressing inequality within and between nations a key focus of its 17 Sustainable Development Goals (SDGs) (UN, 2015).

Over the past two decades, the global economy has undergone notable transformations, including robust economic growth, greater trade integration, and significant capital accumulation. However, these changes have not been translated into equitable benefits for all population segments, particularly in underdeveloped and low-income countries (IMF, 2023). Therefore, lowering income inequality is essential for stabilizing the economy and achieving sustainable development.

The existing literature concerning the dynamics of income inequality and its macroeconomic drivers has yielded mixed findings across various countries and regions (Batuo et al., 2022; Berisha et al., 2018; Deyshappriya et al., 2017; Taresh et al., 2021; Zandi et al., 2022). The direction and magnitude of macroeconomic influences often vary depending on various aspects, including the country's stage of development, income levels, periods, and methodologies applied (Adams and Klobodu, 2019; Batuo et al., 2022; Shahbaz, 2010; Siami-Namini and Hudson, 2019; Zheng et al., 2023). Economic growth, for example, is often regarded as a double-edged sword: while it can reduce poverty, it may also exacerbate income inequality if the resulting wealth is distributed unevenly (Cerra et al., 2021; Lim and Sek, 2014). The pioneering work of Kuznets (1955) revealed controversial findings, indicating that income distribution is more equitable in developed and industrialized economies compared to developing or agrarian countries.

Inflation can diminish purchasing power, often disproportionately affecting lower-income households and exacerbating income (Nantob, 2015; Zheng et al., 2023). While fostering economic growth, trade openness can generate uneven benefits across regions and sectors, further contributing to disparities in income distribution (Dorn et al., 2022). Unemployment can also exacerbate income inequality due to job losses and a lack of economic opportunities (Nayyar, 2014). However, this effect can be mitigated by better institutional quality that can provide more opportunities and support for the unemployed (Law and Soon, 2020). Furthermore, Gross capital formation (GCF), which reflects the investment levels, can stimulate economic activities within and between countries. However, without policies that promote more inclusive wealth distribution, the benefits may disproportionately flow to wealthier segments of the population (Piketty, 2014).

While extensive research has examined how macroeconomic factors affect income inequality in different countries, there is a lack of studies exploring the dynamic effects of these factors collectively, especially in lower-middle-income countries. Furthermore, the latest Sustainable Development Report 2024 highlights that most lower-middle-income economies continue to face significant and persistent challenges in achieving reduced inequalities (Sachs et al., 2024). Given the diverse economic landscapes in these economies, a deeper look at the dynamic relationship between income inequality and key macroeconomic indicators is essential for policymakers seeking to promote equitable societies and inclusive growth. Therefore, the main purpose of this study is to deepen the existing body of research by analyzing the dynamic impacts of five key macroeconomic factors on income inequality in 18 lower-middle-income countries from 1996 to 2018. More specifically, this research seeks to verify the KCH's validity and examine the dynamic effects of inflation, GCF, trade, and unemployment on income inequality.

1 LITERATURE REVIEW

Income inequality is perhaps one of the most significant macroeconomic issues that continuously attract the attention of policymakers, especially in underdeveloped and emerging economies. It is reflected

in various economic dimensions, such as earnings, wages, consumption, expenditure, and income (Goodman and Oldfield, 2004). The theoretical background of income inequality is rooted in classical economic theories, which regarded income inequality as a natural consequence of a free market system (Ricardo, 1817; Smith, 1776). In light of this, Marx (1867) viewed the capitalist system as exploitative, potentially widening the inequality gap, while John Mill advocated for societal intervention to moderate the excesses of capitalism and ensure a fairer income distribution through taxes and social welfare – principles that later formed the basis of welfare economics (Bowden, 2020; Mill, 1982). From a modern theoretical perspective, human capital theory posits that investment in education, skill development, and training is a solution to reducing income disparity (Mincer, 1974; Psacharopoulos and Patrinos, 2018). Recently, proponents of the capability approach have argued that enhancing individuals' capabilities through education and health investments improves economic outcomes and fosters a more equitable distribution of opportunities and resources in society (Nussbaum, 2000; Sen, 1999). Meanwhile, Kuznets (1955) hypothesized an inverted U-shaped linkage between economic growth and income inequality. According to his hypothesis, income distribution initially becomes more unequal during the early stages of the development process, reaching a peak before eventually showing a trend toward becoming more equal as per capita income rises; income inequality begins to decline as wealth becomes more evenly distributed.

The extant literature has widely scrutinized how economic growth impacts income inequality. Some researchers have analyzed this relationship through the prism of validating the KCH. In contrast, others have delved into the traditional framework by examining the individual impact of economic growth on income distribution. Using panel data from 33 Asian countries from 1990 to 2013, Deyshappriya (2017) employed the Generalized Method of Moments (GMM) and identified compelling evidence supporting the KCH. Additionally, Batuo et al. (2022) examined the validity of KCH and other macroeconomic factors by employing static and dynamic panel models for 52 African countries from 1980 to 2017. The countries were divided into four cups concerning income levels. Their findings revealed compelling evidence on the validity of KCH in the least-developed countries, while they found positive and non-linear U-shaped linkage in higher-income countries. Two studies conducted in Indonesia have applied several panel data models indicating that KCH holds in Indonesian provinces (Muryani et al., 2021; Taresh et al., 2020). However, some studies indicated that KCH does not hold but showed a positive linkage between them (Adams and Klobodu, 2019; Berisha et al., 2020). Nonetheless, Asogwa et al. (2022) employed GMM models on a panel of 28 African countries from 2001 to 2016 and demonstrated that this dynamic linkage is insignificant. In Pakistan, Shahbaz (2010) went beyond these relationships. He confirmed that not only did the KCF hold, but also an S-shaped relationship, determined by applying an autoregressive distributed lag (ARDL) model from 1970 to 2005.

As for inflation and income inequality dynamics, economic theory suggests that inflation can affect income inequality negatively and positively. As for the positive effect, inflation diminishes individuals' purchasing power and the real values of their unindexed assets, pensions, and social transfers, thereby disproportionately impacting people with lower income (Balcilar et al., 2018; Glawe and Wagner, 2024; Wolff, 2023). It also distorts income distribution by favoring profit earners over wage earners (Nantob, 2015; Siami-Namini and Hudson, 2019). On the negative side, conversely, inflation may reduce the real value of debt, easing the burden on borrowers, who are typically lower-income individuals, taxing the wealthy, and reducing income from assets (Bulić, 2001; Monnin, 2014; Romer and Romer, 1998; Zheng et al., 2023). Empirical research has shown either negative or positive effects and, in some cases, a nonlinear impact. For example, Galli and van der Hoeven (2001) found that inflation directly impacted income inequality in a sample of 15 OECD countries. Berisha et al. (2023) revealed a negative effect of inflation on income inequality, which intensifies at higher inequality levels. Moreover, Zhang and Ben

Naceur (2019) showed that inflation negatively impacted income inequality in low-income countries. This negative effect was also supported by El Herradi et al. (2023) in 14 OECD economies and Göcen (2024) in 58 countries. However, Albanesi (2007) and Thalassinou et al. (2012) found that inflation positively affected income inequality. Brei et al. (2023) and Zandi et al. (2022) also indicated that inflation positively affected income inequality in high-income countries and Asian developing economies, respectively. Law and Soon (2020) used the GMM panel models from 65 developed and emerging economies from 1987 to 2014 and demonstrated that higher income inequality was positively linked with inflation across both the developed and developing countries. However, this effect is significantly moderated by better institutional quality. Nantob (2015) applied the GMM econometric models utilizing annual panel data from 2001 to 2012 from 45 developing nations and identified that income inequality was nonlinearly linked with inflation and exhibited an inverted U-shaped pattern. The study showed that GDP per capita, political instability, and trade openness significantly mediated this dynamic nexus. Balcilar et al. (2018) identified a nonlinear relationship with a 3% inflation threshold in the US. When inflation exceeds this threshold, it positively influences income inequality, while inflation below this level has a negative effect on income inequality. Likewise, a recent study conducted by Glawe and Wagner (2024) employed dynamic panel threshold models on a sample of 101 economies. It revealed that income inequality increased when inflation exceeds a 6% threshold, while at lower inflation levels, the dynamic relationship was insignificant. A study by Siami-Namini and Hudson (2019) highlighted that inflation effects on income inequality varied depending on the stage of development. They identified an inverted U-shaped link in developing economies and a U-shaped connection in developed countries. In contrast, a recent study by Zheng et al. (2023) suggested that this relationship can be either negative, positive, or U-shaped. This variation depends on the relative prominence of wealth disparities versus skill gaps and how the proportion of interest income to labor income reacts to inflationary pressures. Meniago and Asongu (2018) suggested that inflation could disproportionately impact lower-income groups more adversely than higher-income groups, exacerbating income inequality. This indicates that inflation's impact on income distribution may widen the gap between different socioeconomic groups.

Meanwhile, the literature did not extensively discuss the dynamic effects of other macroeconomic factors, including the GCF, trade, and unemployment. Most previous research has included these variables to control the income inequality equation, whereby empirical findings showed mixed results. Empirical analysis in Asian countries demonstrated that higher income inequality was significantly associated with higher levels of political instability, trade, unemployment, and inflation (Deyshappriya, 2017). In the same way, Zandi et al. (2022) employed a random effect model (REM) and GMM utilizing data from developing Asian countries. They demonstrated that income inequality and unemployment were positively linked. However, Heer and Süßmuth (2003) employed a traditional linear regression model in the US economy. They found no significant linkage between unemployment and income inequality, while applying the error correction model revealed a positive linkage between them. Law and Soon (2020) investigated the dynamics of inflation and income inequality and revealed positive effects of trade openness and foreign direct investment on income inequality but not for unemployment as controlling variables. Using the system GMM panel model for a panel of 58 economies from 2012 to 2018, Göcen (2024) revealed negative effects of per capita GDP and trade openness while unemployment weekly and positively impacted income inequality.

Given the mixed results discussed above and the lack of studies that have examined the dynamic impacts of key macroeconomic indicators like GCF, inflation, per capita GDP, unemployment, and trade collectively, there is a need to explore how these factors influence the dynamics of income inequality. Furthermore, there is a shortage of research examining these dynamic relationships within developing countries, especially in lower-middle-income economies. Therefore, the current research will contribute

to the current body of knowledge by exploring the dynamic relationships between income inequality and these macroeconomic indicators in a group of economies classified as lower-middle-income nations.

2 METHODOLOGY AND DATA

This section outlines the methodological framework guiding our econometric study. It presents the econometric model, the data, and the estimation process.

2.1 Econometric specifications

This study intends to estimate the following income inequality equation:

$$\begin{aligned} \ln(GINI)_{it} = & \beta_0 + \beta_1 \ln(GDPPC)_{it} + \beta_2 (\ln(GDPPC)_{it})^2 + \beta_3 INF_{it} + \beta_4 GCF_{it} + \beta_5 UNEM_{it} \\ & + \beta_6 TRADE_{it} + \varepsilon_{it}, \end{aligned} \quad (1)$$

where i refers to countries, and t denotes the period. $\ln(GINI)_{it}$ is the natural logarithm of the Gini index, which represents the dependent variable of this study. The parameters, β_1 , β_2 , β_3 , β_4 , β_5 and β_6 capture the effects of GDP per capita ($\ln(GDPPC)_{it}$), the squared term of GDP per capita ($(\ln(GDPPC)_{it})^2$), inflation (INF_{it}), GCF (GCF_{it}), unemployment rate ($UNEM_{it}$), trade ($TRADE_{it}$). β_0 denotes a scalar that captures the intercept of the income equation, and the error terms are represented by ε_{it} .

2.2 Data sources

This study employs annual panel data from 1996 to 2018 for lower-middle-income economies, driven by the significant economic and social challenges these countries have confronted. These challenges include efforts to address income inequality and make progress toward reducing disparities, as emphasized by SDG10 (Sachs et al., 2024). The study sample includes 18 lower-middle-income countries from 1996 to 2018, as displayed in Table A1 in the Appendix. The selection of this specific set of 18 lower-middle-income economies was primarily driven by the availability and completeness of the data required for the analysis, particularly the Gini index. While other countries are classified as lower-middle-income by the World Bank, they could not be included in this study due to missing data on key variables. Moreover, extending the study period would have resulted in increased missing data. Therefore, the analysis was limited to the 1996–2018 period to maximize the available data and include as many countries as possible.

The variables used in this study and their sources are shown in Table A2 in the Appendix. In line with the literature, the study utilized the Gini index based on disposable income, extracted from the Standardized World Income Inequality Database (version 9.7), as a proxy measure for income inequality (Solt, 2020). It is expressed in percentage and takes possible values between 0 and 100%. A Gini index value approaching zero indicates less income inequality and more equitable societies, while a value approaching 100% exhibits higher income inequality. The World Bank Development Indicators (WDI) database was the primary source of the five key macroeconomic predictors over the study period. These include per capita GDP adjusted for 2015 prices, GCF as a percentage of GDP, inflation rate based on the consumer price index, unemployment rate calculated based on the International Labor Organization (ILO) estimates, and trade openness calculated as the ratio of net exports and imports to GDP. Furthermore, Table 1 displays the descriptive statistics of the study variables.

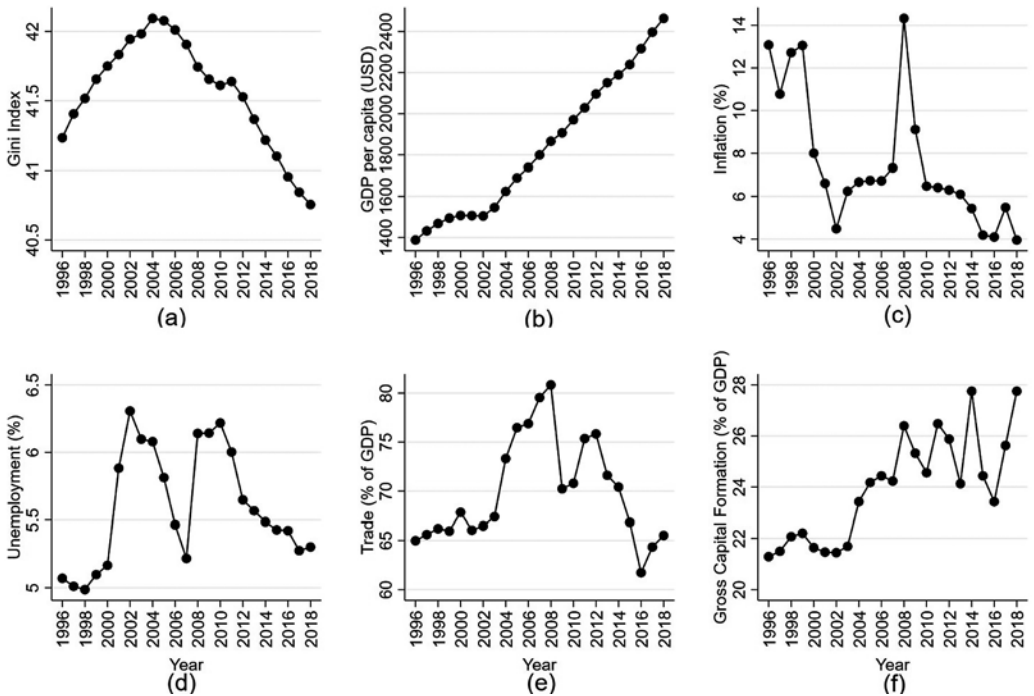
To gain more insight into the dataset, the study provided time series plots for the study variables by averaging the data for each year across all countries. Figure 1(a) shows a time series plot of the annual average Gini index for the entire sample, which indicates that income inequality, on average, increased from 1996 to 2005 and then decreased slightly until 2018. However, the average levels of income inequality across the 18 lower-middle-income economies remained high over the study period.

Table 1 Descriptive statistics for countries and the entire sample

Variable	Gini Index			GDPPC			INF			UNEM			TRADE			GCF			Obs.
	Mean (SD)	Range (Max-Min)	Mean (SD)	Range (Max-Min)	Mean (SD)	Range (Max-Min)	Mean (SD)	Range (Max-Min)	Mean (SD)	Range (Max-Min)	Mean (SD)	Range (Max-Min)	Mean (SD)	Range (Max-Min)	Mean (SD)	Range (Max-Min)			
Bangladesh	32.79 (0.77)	33.5–31.6	903.20 (272.01)	1 460.81–575.04	6.24 (2.29)	11.40–2.01	3.90 (0.66)	5.00–2.51	35.17 (7.42)	48.11–26.08	26.12 (2.93)	31.82–20.73	23						
Bolivia	48.83 (4.79)	54.5–40.8	2 403.48 (421.52)	3 219.20–1 912.00	5.16 (3.34)	14.01–0.93	2.62 (0.46)	3.66–2.02	63.64 (14.28)	85.26–44.17	17.73 (3.15)	23.61–11.02	23						
Cote d'Ivoire	51.63 (2.08)	53.9–47.2	1 736.45 (205.99)	2 168.91–1 507.09	2.42 (1.65)	6.31–0.36	4.97 (1.54)	7.22–1.90	57.29 (6.55)	70.30–46.04	17.56 (3.87)	23.39–12.02	23						
Egypt	39.85 (0.66)	41.4–38.9	2 926.87 (449.27)	3 635.42–2 181.25	9.14 (6.15)	29.51–2.27	10.32 (1.75)	13.15–7.95	46.85 (10.68)	71.68–30.25	17.97 (2.37)	22.39–13.64	23						
Ghana	42.13 (1.02)	43.5–40.2	1 323.47 (319.66)	1 899.81–951.92	18.22 (11.34)	46.56–4.87	6.11 (2.30)	10.4–2.17	81.39 (15.76)	116.05–60.76	21.77 (4.81)	29.00–12.81	23						
Honduras	50.47 (2.39)	53.1–46.4	2 015.77 (228.99)	2 423.28–1 693.72	8.43 (5.19)	23.84–2.72	4.61 (1.17)	7.08–3.16	118.28 (11.73)	136.49–96.91	26.71 (3.85)	36.07–20.60	23						
India	44.22 (1.59)	47.2–41.4	1 122.44 (381.48)	1 891.14–651.96	6.68 (2.98)	13.23–3.33	8.06 (0.42)	8.70–7.15	39.41 (11.37)	55.79–21.93	33.21 (5.41)	41.95–22.76	23						
Jordan	37.48 (0.68)	38.7–36.8	4 176.60 (496.86)	4 920.87–3 477.17	3.37 (3.13)	13.97–(-0.88)	14.01 (1.63)	18.26–11.90	116.14 (17.47)	146.91–87.96	26.97 (4.88)	36.05–20.10	23						
Kenya	45.16 (1.33)	47.1–43.0	1 318.13 (134.73)	1 604.80–1 165.17	9.01 (4.85)	26.24–1.96	2.88 (0.35)	4.28–2.65	50.58 (8.06)	64.48–34.41	18.99 (2.73)	24.95–15.00	23						
Kyrgyzstan	34.63 (1.40)	36.9–32.4	903.73 (180.77)	1 197.61–619.96	10.54 (10.07)	37.03–0.39	2.56 (0.67)	3.67–1.51	108.97 (22.33)	146.11–73.75	25.29 (7.80)	36.76–11.83	23						
Laos	35.93 (0.69)	37.0–35.0	1 433.35 (537.33)	2 467.96–782.96	16.80 (30.08)	125.27–0.14	1.83 (0.71)	3.27–0.71	78.55 (11.36)	99.06–60.57	26.07 (7.98)	34.06–12.95	23						
Pakistan	34.43 (0.20)	34.7–34.1	1 243.75 (173.99)	1 612.84–1 033.88	7.68 (4.35)	20.29–2.53	1.34 (1.25)	4.08–0.40	29.61 (4.62)	38.33–21.46	16.39 (1.25)	19.00–14.63	23						
Palestinian Territories	38.97 (1.36)	41.3–37.2	2 756.25 (491.80)	3 483.10–1 836.97	3.48 (2.60)	9.89–(-0.22)	19.38 (5.39)	27.47–10.35	78.04 (9.64)	96.35–65.42	26.14 (6.59)	42.88–16.66	23						
Philippines	41.60 (1.03)	42.8–39.4	2 331.62 (517.86)	3 439.10–1 776.98	4.46 (2.14)	9.23–0.67	3.49 (0.42)	4.05–2.34	71.87 (10.91)	87.57–55.82	20.30 (3.08)	27.15–15.68	23						
Senegal	41.23 (0.56)	42.2–40.6	1 830.09 (98.75)	1 384.64–980.77	1.57 (2.03)	7.35–(-2.25)	3.38 (1.13)	6.76–2.65	54.49 (5.02)	62.76–46.27	23.44 (3.80)	32.65–15.85	23						
Sri Lanka	47.57 (1.16)	48.5–44.8	2 822.91 (916.81)	4 495.71–1 674.00	8.48 (4.91)	22.56–2.14	6.54 (2.32)	11.35–3.88	64.01 (15.24)	88.64–46.47	28.16 (4.85)	39.73–22.00	23						
Tanzania	44.06 (0.92)	45.3–42.4	733.19 (162.48)	1 012.50–519.06	8.45 (4.56)	20.98–3.49	2.93 (0.88)	3.47–2.13	37.99 (9.73)	56.17–23.99	27.59 (8.83)	38.38–10.26	23						
Vietnam	37.07 (0.32)	37.6–36.4	1 830.09 (638.28)	3 090.77–975.07	6.30 (5.52)	23.12–(-1.71)	1.88 (0.52)	2.87–1.00	127.90 (20.83)	164.66–92.71	32.53 (3.23)	39.57–27.63	23						
Total	41.56 (5.76)	54.5–31.6	1 840.36 (977.34)	4 920.87–519.06	7.58 (9.56)	125.27–(-2.25)	5.60 (4.92)	27.47–0.40	70.01 (32.20)	164.66–21.46	24.05 (6.93)	42.88–10.26	414						

Note: SD – standard deviation; obs. – number of observations.

Source: Own construction

Figures 1(a)–(f) Trends in the mean values of key study variables from 1996 to 2018


Source: Own construction based on WDI (World Development Indicators) and WIID (World Income Inequality Database)

As depicted in Figure 1(b), GDP per capita exhibited a steady upward trend throughout the study period from 1996 to 2018, suggesting overall economic growth and development within the lower-middle-income countries examined in this analysis.

As shown in Figure 1(c), the time series of inflation rates across the entire sample provides insights into the average inflation values. We observed that inflation, on average, followed a downward trend from 1996 to 2002. Furthermore, an increasing trend was observed from 2003 until 2008, culminating in a peak in 2008 due to the global economic crisis. From 2009 to 2018, inflation rates, on average, exhibited a declining trend.

Figure 1(d) presents a time series plot of unemployment for the entire sample. On average, the unemployment rate exhibited cyclical behavior over the study period. On average, from 1996 to 2002, we observed a decreasing trend in unemployment, suggesting improvements in labor market conditions during this period. However, this positive trajectory was followed by an upward trend between 2003 and 2011, driven by the consequences of the Great Recession in 2008–2009 that adversely affected labor markets worldwide. Subsequently, from 2012 to 2018, the unemployment rate resumed declining, reflecting a recovery phase as economies stabilized and labor markets strengthened.

Figure 1(e) illustrates a time series plot of trade for the entire sample. As shown, trade exhibited a steady upward trend from 1996 to 2008. This was followed by a reversal in the trend across the entire sample from 2009 to 2016 before returning to an increasing trajectory from 2017 to 2018.

Finally, Figure 1(f) displays the time series plot of the average GCF of the monitored economies. On average, GCF as a percentage of GDP experienced a steady rise over the period 1996–2008. However,

it exhibited volatility from 2009 to 2016 and then returned to increase from 2017 to 2018. The trend suggests a long-term increase in investment levels as a share of GDP, though interrupted by periods of economic instability and fluctuations.

2.3 Estimation procedure

After collecting the data and confirming the absence of missing values, we conducted preliminary checks on all variables included in this study. Stationarity was assessed using both the Im-Pesaran-Shin (2003) and Phillips-Perron (1988) tests. Results indicated that all variables were stationary at their first difference, demonstrating an integration order of one $I(1)$, as illustrated in Table A3 in the Appendix. Furthermore, residual cointegration tests were employed by Kao (1999) and Pedroni (1999) to investigate whether the study variables are cointegrated. The findings of both tests revealed that the null hypothesis of no cointegration among variables was rejected, and we concluded that a long-run equilibrium relationship existed among the variables in our panel (Table A4). Additionally, the study identified no multicollinearity among the independent predictors by examining the correlation matrix (Table A5).

For estimating the long-run coefficients while addressing issues of endogeneity and serial autocorrelation, the study employed FMOLS and DOLS econometric models (Phillips and Hansen, 1990; Stock and Watson, 1993). These methods were utilized for their appropriateness in panel data analysis and their ability to provide reliable estimates of the relationships among the variables, particularly in the context of cointegrated nonstationary time series data, allowing for robust estimation of the long-run effects of macroeconomic factors on income inequality. Kao and Chiang (2000) suggested that DOLS performs better than FMOLS in homogeneous and heterogeneous panels, regardless of sample size. A key distinction between these methods is that FMOLS involves non-parametric adjustments of the regressors, whereas DOLS uses parametric adjustments.

For the panel regression model presented by Formula (1), the FMOLS estimator is given by:

$$\hat{\beta}_{FMOLS} = \left[\sum_{i=1}^N \sum_{t=1}^T (X_{it} - \bar{X}_i) \right]^{-1} \left[\sum_{i=1}^N \sum_{t=1}^T (X_{it} - \bar{X}_i)(y_{it} - \bar{y}_i + \Delta_{it}) \right], \quad (2)$$

where $i = 1, \dots, N$, and $t = 1, \dots, T$ denote the cross-sections and periods, respectively. X_{it} denotes the vector of independent variables, and \bar{X}_i are the means of X_{it} . y_{it} represents the dependent variable, and \bar{y}_i its average. Δ_{it} is the correction term for serial autocorrelation and potential endogeneity. Meanwhile, DOLS includes leads and lags of the differenced predictors to account for endogeneity and serial correlation. The DOLS estimator is given by:

$$\hat{\beta}_{DOLS} = \left[\sum_{i=1}^N \sum_{t=1}^T Z'_{it} Z_{it} \right]^{-1} \left[\sum_{i=1}^N \sum_{t=1}^T Z'_{it} y_{it} \right], \quad (3)$$

where Z_{it} represents the augmented regression matrix $(X_{it}, \Delta X_{it+q}, \dots, \Delta X_{it-q})'$ such that ΔX_{it+q} and ΔX_{it-q} are leads and lags of the first differences of the regressors X_{it} .

Both FMOLS and DOLS estimators produce t-statistics and corresponding p-values, which are used to assess the statistical significance of the estimated coefficients. As reported in the econometric literature, the statistical significance of the estimated parameters is assessed at the 1%, 5%, and 10% levels, indicating highly, moderately, and weakly significant effects, respectively, for rejecting the null hypothesis of no long-run effect.

2.4 Robustness check

To validate the estimated long-run coefficients, the current study employs mean group (MG) and pooled mean group estimators (Pesaran and Smith, 1995). The MG and PMG estimators are estimated using the ARDL modelling approach, which estimates both the long-run and the short-run effects. The PMG and MG methods differ in how they address estimator heterogeneity. In PMG, homogeneity is assumed only in the long-run relationship, but short-run coefficients and error variances vary across groups. In MG, meanwhile, both short-run and long-run coefficients differ across groups, making it more flexible in accounting for heterogeneity in panel data models. Pesaran et al. (1999) demonstrated that when the long-run homogeneity is presumed, the MG estimator becomes less efficient than the PMG estimator. However, the study focuses only on long-run estimates to compare with FMOLS and DOLS, as the latter estimators do not have short-run estimates.

The Hausman test assesses the efficiency and consistency of different estimators and whether their long-run coefficients exhibit homogeneity across groups, guiding which estimator best fits the data. The test examines the null hypothesis that states that the MG estimator yields results similar to the PMG. Upon rejecting the null hypothesis, it can be concluded that the MG estimator is more efficient and reliable than the PMG (p-value < 0.05). Otherwise, the PMG estimator is preferred (Hausman, 1978). The test statistic of this test can be calculated using the following formula:

$$H = [\hat{\gamma}_e - \hat{\gamma}_c]' [Var(\hat{\gamma}_e) - Var(\hat{\gamma}_c)]^{-1} [\hat{\gamma}_e - \hat{\gamma}_c], \tag{4}$$

where the estimator $\hat{\gamma}_e$ represents the value under the assumption of the null hypothesis (i.e., PMG), $\hat{\gamma}_c$ denotes the alternative estimator under the alternative hypothesis (MG), and $Var(\hat{\gamma}_e)$ and $Var(\hat{\gamma}_c)$ are the variance-covariance matrices of the two estimators.

3 RESULTS AND DISCUSSION

Table 2 shows the results obtained from FMOLS and DOLS estimation methods, which aimed to elucidate the nuanced long-term relationships among the variables examined in this study. Both FMOLS and DOLS estimators converge to reveal remarkable similarity and consistent estimates of the long-run parameters. The adjusted R-squared values were 73.8% for the FMOLS model and 80.2% for the DOLS model, demonstrating a good fit for the data.

Table 2 Long-run estimated parameters using FMOLS and DOLS

Variable	FMOLS				DOLS			
	Coefficient	S.E.	t-statistic	p-value	Coefficient	S.E.	t-statistic	p-value
Ln(GDPPC)	0.971***	0.027	36.118	0.000	1.076***	0.063	17.056	0.000
Ln(GDPPC)^2	-0.061***	0.004	-17.505	0.000	-0.072***	0.009	-7.198	0.000
INF	0.198***	0.025	7.965	0.000	0.189***	0.036	5.254	0.000
UNEM	0.249***	0.021	11.857	0.000	0.236***	0.042	5.619	0.000
TRADE	0.281***	0.064	4.413	0.000	0.269***	0.059	4.559	0.000
GCF	-0.001	0.002	-0.500	0.617	-0.005	0.004	-1.251	0.422
R-Squared	0.764				0.826			
Adjusted R-Squared	0.738				0.802			

Notes: *, **, and *** denote rejection of the null hypothesis of no long-run effect at the 10, 5, and 1% significance levels, respectively.
 Source: Own construction

The empirical analysis reveals that the long-run effects of GDPPC and its quadratic term are statistically significant, validated by a 1% significance level using both estimators. Specifically, using the FMOLS estimator, the estimated long-run coefficients of $\ln(\text{GDPPC})$ and its quadratic term are 0.971 and -0.061 , respectively. Likewise, the DOLS estimation demonstrates that the coefficients of $\ln(\text{GDPPC})$ and its squared term are 1.076 and -0.072 , respectively. The positive and negative coefficients of $\ln(\text{GDPPC})$ and its squared term, respectively, demonstrate the nonlinear inverted U-shaped relationship between economic growth and income inequality within the studied lower-middle-income countries, which confirms the validity of the KCH in these economies. This suggests that, in lower-middle-income economies, income inequality initially rises with increasing GDP per capita but starts to decline once GDP per capita exceeds a specific threshold. Our empirical results are similar to several previous findings, including Deyshappriya (2017) for Asian economies, Muryani et al. (2021) and Taresh et al. (2020) for Indonesian provinces, Younsi and Bechtini (2020) for BRICS economies, and Younsi et al. (2022) for Asian and South African nations. The current results are also congruent with those of Batuo et al. (2022) for underdeveloped economies but contradict their findings for developed countries. In contrast, our results are dissimilar to the findings of Asogwa et al. (2022), who invalidate the KCH and did not even find any significant effect of per capita GDP on income inequality in their panel of 28 African economies.

The FMOLS and DOLS estimators reveal a substantial and positive relationship between inflation and income inequality, which is statistically significant at the 1% significance level. This indicates that higher inflation exacerbates income inequality within the studied economies. According to FMOLS analysis, a 1% increase in inflation corresponds to a 0.198% increase in income inequality. Similarly, the DOLS model indicates that a 1% increase in inflation leads to a 0.189% increase in income inequality in lower-middle-income economies. Our results align with several previous studies that suggest inflation exacerbates income inequality (Albanesi, 2007; Balcilar et al., 2018; Brei et al., 2023; Deyshappriya, 2017; Law and Soon, 2020; Nantob, 2015; Thalassinos et al., 2012; Younsi and Bechtini, 2020; Younsi et al., 2022; Zandi et al., 2022). The current finding is also consistent with the study by Clarke et al. (2006), which suggests that inflationary instability disproportionately affects the poor and middle class compared to the wealthy. The latter group benefits from greater access to financial tools that help diminish inflation's impact. Thus, this study confirms that inflation diminishes purchasing power for lower-income households and disrupts income distribution (Balcilar et al., 2018; Nantob, 2015). However, this study contradicts those that found a negative effect of inflation on income inequality (Berisha et al., 2023; Bulíř, 2001; El Herradi et al., 2023; Göcen, 2024; Monnin, 2014; Romer and Romer, 1998; Zhang and Ben Naceur, 2019).

The current analysis also reveals that both the FMOLS and DOLS models indicate that unemployment positively influences income inequality, highlighting the increasing impact on income inequality in the studied group of lower-middle-income countries, evidenced by a 1% significance level. According to the FMOLS estimation, a 1% increase in the unemployment rate corresponds to a 0.249% increase in income inequality. Similarly, the DOLS analysis indicates that a 1% rise in the unemployment rate leads to a 0.236% increase in income inequality within lower-middle-income countries. This empirical finding is congruent with several previous findings (Deyshappriya, 2017; Heer and Süßmuth, 2003; Zandi et al., 2022). In the meantime, Göcen (2024) and Monnin (2014) demonstrated a weak positive impact of unemployment on income inequality. The findings of Law and Soon (2020), who found no significant linkage between income inequality and unemployment, were dissimilar to our results.

The empirical findings of both FMOLS and DOLS reveal that trade significantly and positively impacts income inequality at a 1% level of significance within the group of lower-middle-income countries analyzed in the current investigation. The FMOLS estimation shows that a 1% rise in trade is associated with a 0.281% increase in income inequality. The DOLS estimation mirrors this finding, indicating that a 1% increase in trade is linked to a 0.269% rise in income inequality. Our results are congruent with the findings of Adams and Klobodu (2019), Deyshappriya (2017), and Law and Soon (2020). The results do not strongly

support the notion that trade openness reduces income inequality in underdeveloped economies, which often have a larger proportion of human resources and primary education than developed economies (Topalova, 2007). Meanwhile, Gourdon et al. (2008) highlighted that trade openness had an increasing effect in high-income countries while decreasing in low-income countries. A comparative study by Yang and Greaney (2017) suggested mixed results, showing that trade openness reduces income inequality in Japan and the US, increases it in China, and has no impact in South Korea. Göcen (2024) showed that trade openness negatively influences income inequality, which contradicts our results.

Finally, this study finds no statistically significant effect of GCF on income inequality in the long run, as indicated by the FMOLS and DOLS estimators. The results suggest that higher investment levels as a share of GDP are not associated with a reduction in income inequality in the long-run for the group of lower-middle-income countries examined. This finding aligns with the results of Deyshappriya (2017) in a study of 33 Asian economies. However, our results differ from previous findings (Alesina and Perotti, 1996; Batuo et al., 2022). For example, Batuo et al. (2022) found a robust negative effect of investment measured by GCF in a sample of 52 African countries regardless of their income. The lack of a significant long-term relationship between GCF and income inequality suggests that simply increasing investment may not address income disparities in these economies.

3.1 Results of robustness check

The estimation results of MG and PMG models are shown in Table 3. The insignificant results of the Hausman test ($H = 9.891$, $p\text{-value} = 0.129$) demonstrate that the PMG estimator is more efficient than the MG estimator for the current dataset. Consequently, the long-run coefficients estimated using the PMG method are compared with those obtained from FMOLS and DOLS. The findings of the PMG-ARDL estimator align closely with those derived from FMOLS and DOLS methods, further confirming the robustness of the study’s findings. The consistency observed across the FMOLS, DOLS, and PMG-ARDL estimators highlighted the reliability of the long-run relationships between macroeconomic variables and income inequality in lower-middle-income countries.

Table 3 Estimated long-run coefficients using MG and PMG estimators

Variable	PMG				MG			
	Coefficient	S.E.	t-statistic	p-value	Coefficient	S.E.	t-statistic	p-value
Ln(GDPPC)	1.494***	0.270	5.533	0.000	1.330***	0.260	5.115	0.000
Ln(GDPPC) ²	-0.100***	0.017	-5.882	0.000	-0.095***	0.015	-6.333	0.000
INF	0.154***	0.056	2.750	0.006	0.135*	0.072	1.875	0.062
UNEM	0.225**	0.102	2.206	0.026	0.306	0.227	1.348	0.178
TRADE	0.381***	0.049	7.776	0.000	0.423**	0.198	2.137	0.033
GCF	-0.003	0.004	-0.754	0.451	0.008	0.007	1.143	0.254

Note: Hausman test ($H = 9.891$, $p\text{-value} = 0.129$).
Source: Own construction

The PMG estimation results show that the long-run coefficients for the logarithm of GDP per capita and its squared term are 1.494 and -0.100, respectively, both significant at the 1% level. These findings further validate the KCH within the examined lower-middle-income nations. Additionally, the positive long-run coefficient of 0.154 for inflation suggests that a 1% increase in the inflation rate leads to a 0.154% rise in income inequality, also significant at the 1% level. The analysis also indicates a positive long-run impact of unemployment on income inequality, with a coefficient of 0.225, significant at the 5% level. This implies that a 1% increase in the unemployment rate results in a 0.225% increase in income inequality.

Furthermore, the results demonstrate a statistically significant positive long-run relationship between trade openness and income inequality at the 1% significance level. Specifically, a 1% increase in trade leads to a 0.381% rise in income inequality within the analyzed lower-middle-income countries. However, the PMG analysis shows no statistically significant long-run impact of GCF on income inequality in the examined lower-middle-income economies.

CONCLUSION AND POLICY IMPLICATIONS

The current study investigated the dynamics of income inequality by focusing on the impact of macroeconomic factors on income inequality in 18 selected lower-middle-income economies covering the period from 1996 to 2018. The FMOLS and DOLS models were applied to estimate the long-run relationships among study variables. The PMG-ARDL model was employed to validate the robustness of the estimated relationships in the long run. The results of this study provided compelling evidence that the KCH holds for the examined lower-middle-income economies. This study also demonstrated that inflation, trade, and unemployment significantly exacerbate income inequality. However, the long-run effect of GCF was insignificant. The novelty of this study resides in its comprehensive examination of the macroeconomic contributing factors to income inequality in the examined lower-middle-income economies using advanced panel time-series techniques. Furthermore, the findings of this study can inform policymakers and governments in these nations how to develop more effective strategies and initiatives for reducing income inequality and fostering inclusive economic growth. This aligns directly with the SDGs provided in the UN Agenda for 2030, particularly SDG 10, which aims to achieve reduced inequality within and among nations. Finally, by providing evidence-based policy recommendations for addressing the macroeconomic influences on income inequality, this study can significantly contribute to achieving this global goal.

A key policy implication of this study is the critical need to reduce income inequality within lower-middle-income countries. Policymakers should carefully consider the distributional consequences of macroeconomic policies and integrate equity concerns into their decision-making process. Specifically, policymakers should prioritize investing in human capital, promote progressive taxation, enhance social safety nets, and ensure equal resource access and trade practices. Implementing effective monetary policies that maintain low and stable inflation can bolster the purchasing power of lower and middle-class households, ultimately narrowing income disparities. It is crucial to implement price stabilization programs for essential goods and services to protect vulnerable populations from the detrimental effects of inflation. Moreover, policies to lower unemployment rates should be implemented through job creation initiatives, vocational training programs, and fair wage policies, thereby strengthening labor market resilience. Our study highlights the need for policymakers to adopt a more holistic approach, combining these issues with redistributive policies and skill development to narrow income disparities.

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APPENDIX

Table A1 List of countries

Bangladesh	India	Palestinian Territories
Bolivia	Jordan	Philippines
Cote d'Ivoire	Kenya	Senegal
Egypt	Kyrgyzstan	Sri Lanka
Ghana	Laos	Tanzania
Honduras	Pakistan	Vietnam

Source: Own construction

Table A2 Description of variables and data sources

Variable	Description	Data source
Gini Index	Gini index as a measure of income inequality. Estimate of Gini index of inequality in equivalized (square root scale) household disposable (post-tax, post-transfer) income.	WIID (Solt, 2020)
GDPPC	Gross domestic product (constant 2015 U.S. dollars) divided by midyear population.	WDI
Inflation	Inflation, as measured by the consumer price index, reflects the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly. It is a measure of macroeconomic stability.	WDI
Unemployment	The total number of unemployed divided by the labour force (modelled ILO estimate).	WDI
GCF	Gross Capital Formation consists of outlays on additions to the economy's fixed assets (including land improvements) plus net changes in inventories. The variable is presented as a percentage of GDP.	WDI
Trade	Trade is the sum of exports and imports of goods and services measured as a share of gross domestic product.	WDI

Note: WDI – World Development Indicators, WIID – World Income Inequality Database.

Source: Own construction

Table A3 Results of unit root tests

Variable	IPS W-stat		PP Fisher (X^2)		Result
	Level	1 st difference	Level	1 st difference	
Ln(GINI)	-1.506	-8.645***	12.161	85.417***	I(1)
Ln(GDPPC)	-0.766	-3.517***	24.766	172.573***	I(1)
(Ln(GDPPC))^2	-0.781	-3.460***	25.078	168.370***	I(1)
INF	-1.353*	-4.737***	11.263	143.111***	I(1)
UNEM	0.497	-3.772***	28.428	347.212***	I(1)
TRADE	1.517	-5.533***	20.359	190.675***	I(1)
GCF	0.952	-7.099***	25.812	233.131	I(1)

Note: *, ** and *** denote rejection of the null hypothesis of unit root at the 10, 5 and 1% significance levels, respectively.

Source: Own construction

Table A4 Results of panel cointegration tests

Pedroni panel cointegration test	Statistic	p-value
Within dimension (panel statistics)		
Panel v-statistic	6.958****	0.002
Panel rho-statistic	-1.242	0.916
Panel PP-statistic	-7.273***	0.000
Panel ADF-statistic	-5.317***	0.002
Between dimension (individual statistics)		
Group rho-statistic	3.147	0.957
Group PP-statistic	-6.268***	0.000
Group ADF-statistic	-5.735***	0.000
Results of Kao residual cointegration test		
Panel ADF statistic	-5.867**	0.000***

Note: *, ** and **** denote rejection of the null hypothesis of no cointegration at the 10, 5 and 1% significance levels, respectively.

Source: Own construction

Table A5 Correlation matrix

	Ln(GINI)	LN(GDPPC)	INF	UNEM	TRADE	GCF
Ln(GINI)	1.00					
Ln(GDPPC)	-0.56	1.00				
INF	0.38	-0.21	1.00			
UNEM	0.43	0.37	-0.10	1.00		
TRADE	0.49	0.34	0.08	0.12	1.00	
GCF	0.08	0.05	-0.10	0.06	0.34	1.00

Source: Own construction

Institutions and Free Trade Agreements as Determinants of Trade Potential of India: a Stochastic Frontier Gravity Model Analysis

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Abstract

This study examines how institutions and free trade agreements affect India's actual export and import potential using a panel data set of 40 nations for the years 2000–2022. A simultaneous single-step stochastic frontier model was generated in order to determine the trade efficiency (actualized trade potential). A system generalized method of moments estimator was then used to calculate the influence of institutions and free trade agreements. The results indicate that average export efficiency and import efficiency were found to be approximately 76% and 57%, respectively. Bilateral Free Trade Agreements are positively correlated with the trade efficiency while Multilateral Free Trade Agreements produce negative or insignificant results. The institutional-distance variables yield distinct outcomes for import efficiency and export efficiency.

Keywords

Trade potential, institutional distance, FTA, Gravity Model, Stochastic Frontier Model, GMM

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F02, F14, F15

INTRODUCTION

Trade potential is not the average trade, as was previously defined in the traditional gravity model research, but rather the maximum volume of trade that could be completed in the absence of trade barriers (Armstrong, 2007). Nevertheless, in reality, trade potential is rarely fully realized; trade efficiency

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is the measure of how much trade potential is realized. Tariffs and quotas are examples of protectionist trade policies and are termed as formal impediments to trade in the literature, these formal impediments have an impact on trade efficiency. These trade barriers, however, do not adequately account for the fact that trade is far lower than it should be. McCallum (1995) finds that social structures such as political systems, property rights, contract enforcement etc, prevailing in a country play a significant role in trade flows between nations. These social structures are termed as Institutions in economic literature. These institutions act as informal resistances to trade.

Free Trade Agreements (FTAs) are defined as reciprocal trading arrangements between two or more parties, irrespective of their geographical proximity (WTO). These agreements facilitate an increase in trade among partner countries by alleviating policy-imposed trade restrictions. Furthermore, FTAs are regarded as factors that reduce the barriers to trade (Frankel et al., 1997).

The impact of informal resistances is captured by making use of institutional-distance on trade efficiency. Institutions are the humanely created restraints that govern human relationships and are categorised into formal and informal institutions. Formal Institutions establish the rules that govern the economic activity and thereby lowering the uncertainty, risk and transaction costs. While informal institutions also aid in coordinating economic activity and become especially significant when there are no strong formal market institutions. Accordingly, scholars have considered two types of Institutions-distance: formal and informal (Kostova et al., 2019). This study makes use of World Governance Indicators given by World Bank for Formal Institutional-Distance (referred as ID here onwards) and Cultural indexes given by Hofstede for the Informal Institutional-Distance (referred as CD here onwards).

Trade is a major part of Indian economy. India both exports and imports a significant amount of goods. Since gaining its independence, the value of India's exports as well as its imports has increased. When it comes to signing free trade agreements with its trading partners, India is a cautious and tardy starter. India opted for a strict protectionist import substitution policy up until the early 1990s, which discouraged foreign trade and prevented India from joining any FTAs. India first joined an FTA in 1995 when it joined SAPTA after liberalising its economy and opening it up to international trade in 1991. This was followed in 1998 by India's first bilateral FTA with Sri Lanka. The majority of the FTAs with India date from the 2000s. The rationale for India to enter a free trade agreement are to diversify and increase export markets, to obtain relatively cheaper access to raw materials, intermediate goods, and capital goods, to open up new avenues services industry in India, to bring in foreign investment, to boost manufacturing, generate employment, and bolster competitiveness, and to implement its geopolitical strategy, such as the "Act East" policy. India has pursued a mix of bilateral and regional agreements, focusing on strategic partnerships and economic cooperation with various countries and regions. Over the years, India has entered with a focus on strategic alliances and economic cooperation, India has pursued a variety of bilateral and regional agreements. India has signed numerous trade agreements over the years. India is a member of 18 Regional Trade Agreements (RTAs) in effect as of 2022 with various nations and regions, such as Mauritius, the United Arab Emirates, Australia, South Korea, Japan and ASEAN nations. Additionally, tentative announcements have been made for four more RTAs. Since the commencement of Regional Trade Agreements (RTAs), India's trade has experienced a positive trajectory, diversifying into multiple forms of trade agreements.

To the best of our knowledge, this paper is the first to offer a detailed analysis of the impact of institutional distance on India's trade potential. Secondly, methodologically, this paper contributes as we use a single-step estimation technique of the frontier model to derive trade efficiency by using the less restrictive assumption of a truncated normal distribution for inefficiency. We also include dynamism in the efficiency model by making use of system GMM estimation, which is an improvement over other studies where a two-step approach with a half-normal distribution is used to derive inefficiency and then dynamism is included in the model, or a static stochastic frontier model is estimated.

1 REVIEW OF LITERATURE

When analysing India's trading potential, it is important to consider how institutions and Free Trading Agreements (FTAs) influence trade flows. A thorough grasp of how trade agreements and institutional quality affect trade efficiency and trends can be obtained from a well-organized literature review. Studies that have already been done on the gravity model of trade emphasize how crucial institutional strength is to lowering transaction costs and improving trade facilitation. In the meanwhile, studies on free trade agreements highlight how they promote economic integration and increase market access. This study expands on previous empirical findings by utilizing a Stochastic Frontier Gravity Model to evaluate India's trade potential while taking institutional and policy-related restrictions into consideration.

1.1 Free Trade Agreements and trade potential

Ravishankar and Stack (2014) enhance the traditional Gravity Model by incorporating a Stochastic Frontier approach, introducing a one-sided error term within the composite disturbance term to evaluate the trade potential between Eastern and Western European countries from 1994 to 2007. Their findings indicate that increased trade integration between these regions leads to a greater realization of frontier trade, with Eastern member states achieving, on average, two-thirds of the frontier estimates during the study period. Kumar and Prabhakar (2017) apply Stochastic Frontier specification of the Gravity Model to commodity-level trade, examining the influence of specific FTAs on India's export and import efficiency from 2000 to 2014. They conclude that India realized 60% of its export potential and 50% of its import potential on average during this timeframe. Kaushal (2022) utilizes the Stochastic Frontier Gravity Model to assess the impact of RTAs on India's export efficiency from 2008 to 2018, finding that while India has not fully realized its export potential, RTAs have significantly contributed to enhancing it. Doan and Xing (2017) employ the Stochastic Frontier Gravity Model to evaluate Vietnam's export efficiency to major trading partners from 1995 to 2013, also exploring the effects of FTAs and Rules of Origin. They determine that Vietnam's exports fall short of potential, with FTAs positively influencing export efficiency, whereas Rules of Origin have a negative impact. Abdullahi et al. (2022) assess the efficiency of China's agricultural exports to 114 countries from 2000 to 2019 using the Stochastic Frontier Gravity Model, revealing that China has, on average, 51% untapped export potential in its agricultural sector.

1.2 Institutional-distance and trade

Linders et al. (2004) describe cultural distance and as the differences in shared norms and values between two regions. Their study reveals that cultural distance positively influences trade, whereas institutional distance has a negative impact. Mohamued et al. (2022) examine the effect of institutional distance on China's outward foreign direct investment (FDI) towards African nations, concluding that institutional distance directly correlates with increased FDI flow and therefore inversely with the trade. Xu and Shenkar (2004) suggest that institutional and cultural distances have complementary effects. Kim and Park (2019) define institutional distance as the disparity in institutional quality between regions, noting that such disparities are positively associated with trade costs, particularly in contract-intensive industries, although the overall impact on trade costs is mixed. Vu Hong Van et al. (2022) employ a System GMM estimator, finding that institutional distance negatively affects bilateral trade between countries with high institutional quality, while it positively impacts trade where one or both countries have low institutional quality. T Long et al. (2023) utilize the Gravity Model with System GMM for China's exports, concluding that both cultural and institutional distances negatively affect China's trade. Doanh et al. (2022) use stochastic model to derive the efficiency for half-normal distribution of the inefficiency and the effect of institutional and cultural distances on trade efficiency is estimated separately by system GMM. They

conclude that both institutional and cultural distances impact trade efficiency negatively. Kostova et al. (2019) highlight that the effects of institutional distance vary depending on the home and host countries, and it does not uniformly or negatively influence all cross-border phenomena.

2 RESEARCH METHODOLOGY

This study utilizes a stochastic frontier adaptation of the Gravity model to evaluate India's trade potential and factors influencing it. The Gravity Regression is employed to forecast bilateral trade between partner regions, having emerged in the 1960s as an empirical tool without theoretical foundation. Anderson (1979) is acknowledged for introducing the theoretical basis of the Gravity Model, which was further developed by Anderson and Van Wincoop (2003) to incorporate Multilateral Resistance terms. Baldwin and Taglioni (2006) assert that the derivation by Anderson and Van Wincoop (2003) is applicable solely to cross-sectional data, and they propose a similar Gravity Equation for panel data.

The estimation of trade potential is conducted using the Stochastic Frontier specification of the Gravity Regression, as proposed by Kalirajan (1999, 2007). This approach is derived from the Stochastic Frontier Model, initially applied to assess production efficiency. The frontier model was introduced by Aigner et al. (1977), and Meeusen and Van Den Broeck (1977), with Aigner et al. (1977) presenting a linear model for estimating the production function using cross-sectional data. This model includes a production function regression with a composite error term, consisting of a random disturbance term distributed as $N(0, \sigma^2)$ and an independent one-sided error term. Battese and Coelli (1988) applied the Stochastic Frontier Model to a production function defined for panel data, using three-year data from Australian Dairy Farms to estimate a model of time-invariant inefficiency. Cornwell et al. (1990) developed a time-varying inefficiency Stochastic Frontier model using 12-year panel data from the US Airlines, thereby eliminating the time-invariance constraint. The log-linearised form of gravity model is as following:

$$\ln x_{ij} = \beta_0 + \beta_1 \ln GDP_i + \beta_2 \ln GDP_j + \beta_3 Dist_{ij} + v_{ij}, \quad (1)$$

where x_{ij} stands for bilateral trade (exports/imports) GDP_i and GDP_j are the respective GDPs of the trading partners, $Dist_{ij}$ is the geographical distance between the countries, \ln is the natural logarithm, $\beta_0, \beta_1, \beta_2$ and β_3 are the parameters to be estimated the sign of β_3 is negative.

The Stochastic Frontier specification of the Gravity Model in Formula (1) proposed by Kalirajan (1999, 2007) with composite error term composed of two distinguishable random disturbance terms for estimating the Frontier (potential) trade and there from trade efficiency is as following:

$$\ln x_{ij} = \beta_0 + \beta_1 \ln GDP_i + \beta_2 \ln GDP_j + \beta_3 Dist_{ij} + \varepsilon_{ij}, \quad (2)$$

$$\varepsilon_{ij} = (v_{ij} - u_{ij}), \quad (3)$$

where ε_{ij} is the composite error term composed of v_{ij} the conventional random disturbance term distributed independently and identically distributed as $N(0, \sigma_v^2)$ and u_{ij} which is random variable derived from truncation of normal distribution, truncated above zero as $N^+(\mu_{ij}, \sigma_{ij}^2)$. v_{ij} and u_{ij} are independently distributed of each other. The rationale behind this specification of error terms is that Trade Potential is subject to two distinguishable random disturbances one v_{ij} incorporates the measurement error which allows the Trade Potential to vary and the other u_{ij} the Inefficiency factor reflects the fact that the value of Trade must be equal to or less than the Trade Potential as mentioned by Aigner (1977).

This study employs Battese and Coelli (1995) version of panel data model. The model differs from the earlier empirical studies in that it is a single stage simultaneous estimation procedure while earlier studies adopted a two-stage estimation procedure. In the two-stage estimation, the first stage involved estimation of the Frontier Function and prediction of Inefficiency and the second stage involved estimation of the regression for predicted Inefficiency. The panel data model specification is as following:

$$\ln x_{ijt} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{jt} + \beta_3 Dist_{ijt} + v_{ijt} - u_{ijt}, \tag{4}$$

where the symbols and subscripts mean the same as in Formula (3), subscript t represents the time variable indicating that model (4) is a panel data Stochastic Frontier Gravity Model. u_{ijt} the Inefficiency part is assumed to be a function of unquantifiable variables such as Socio-Political and Institutional factors and FTAs such that:

$$u_{ijt} = \delta z_{ijt} + w_{ijt}, \tag{5}$$

where z_{ijt} are the explanatory variables for Inefficiency component and δ is the vector of parameters to be estimated. w_{ijt} is the random disturbance term truncated from normal distribution $N(0, \sigma^2)$ and the point of truncation is $-\delta z_{ijt}$. Trade efficiency defined by Battese and Coelli (1995) is:

$$TE_{ijt} = \exp(-u_{ijt}). \tag{6}$$

The single stage simultaneous estimation of Stochastic Frontier Gravity Model is carried by method of Maximum Likelihood. The Likelihood function for the Stochastic Frontier Models, with composite error terms is given in Kumbhakar and Lovell (2000). After deriving the trade efficiency from single stage estimation of stochastic frontier model we include the dynamism in the efficiency model by using Blundell and Bond (1998) system GMM approach to small-sample correction. The dynamic model we estimate is following:

$$TE_{ijt} = \alpha_1 TE_{ijt-1} + \alpha_2 Z_{ijt} + \epsilon_{ijt}, \tag{7}$$

where TE_{ijt} is the trade efficiency in period t , TE_{ijt-1} is the trade efficiency in the previous period, Z_{ijt} are the determinants of trade efficiency, ϵ_{ijt} is the random disturbance term, α 's are the parameters to be estimated.

3 ANALYSIS AND DISCUSSION

The Stochastic Frontier Gravity model estimated is:

$$\ln x_{ijt} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{jt} + \beta_3 \ln Dist_{ijt} + \beta_4 comlang + \beta_5 contig + \beta_6 comcol + v_{ijt} - u_{ijt}, \tag{8}$$

where u_{ijt} the Trade Inefficiency component is assumed to be a function defined by:

$$u_{ijt} = \delta_1 FTA_{ijt} + \delta_2 AIFTA_{ijt} + \delta_3 SAFTA_{ijt} + \delta_4 CD_{ij} + \delta_5 ID_{ijt} + w_{ijt}. \tag{9}$$

The dynamic model of trade efficiency estimated is:

$$TE_{ijt} = \alpha_1 TE_{ijt-1} + \alpha_2 FTA_{ijt} + \alpha_3 AIFTA_{ijt} + \alpha_4 SAFTA_{ijt} + \alpha_5 CD_{ij} + \alpha_6 ID_{ijt} + w_{ijt}, \tag{10}$$

where:

- in Formula (8) x_{ijt} represents bilateral trade flows (Imports or Exports) between India and each of its partner country in time t . GDP_{it} and GDP_{jt} represent GDPs of India and each of its partner countries in time t respectively $Dist_{it}$ is the geographical distance between capital cities of India and each of its partner countries. $comlang$ is the dummy for common official language of India and its trading partner which takes the value = 1 if two countries share the same official language and = 0 otherwise $contig$ is the dummy for contiguity that takes the value = 1 if India and its Partner country share border and = 0 otherwise. $comcol$ is the dummy which takes the value = 1 if India and its partner country had the same coloniser in the past and = 0 otherwise.
- in Formulas (9) and (10) CD_{ij} is the cultural distance between India and each of its partner countries. ID_{ijt} is the institutional distance between India and each of its partner countries in time t . FTA_{ijt} is the dummy for bilateral Free Trade Agreements which takes the value = 1 if India and its trading partner have a free trade agreement in operation in time period t and = 0 otherwise $AIFTA_{ijt}$ is the dummy variable for India-ASEAN Free Trade Agreement which takes the value = 1 if India and its partner country are members of AIFTA in time period t and = 0 otherwise $SAFTA_{ijt}$ is the dummy variable for South Asian Free Trade Agreement whose value = 1 if both India and its Partner country are members of SAFTA in time period t and its value = 0 otherwise.

In Formula (10) TE_{ijt} is the trade efficiency and TE_{ijt-1} is the trade efficiency of the previous year. $\beta's, \alpha's, \delta's, v_{ijt}, u_{ijt}$ and w_{ijt} in Formulas (8), (9) and (10) are same as explained earlier.

Data for bilateral trade flows (Imports and Exports) are taken in 1 000 current US\$ from UN Comtrade. UN Comtrade has a “reporter-partner” structure, wherein each country reports trade in 1 000 current US\$ with its partner countries in terms of both exports and imports. We take the data with India as reporter country. Data for GDPs, of India as well as of each of its trading partners is taken from the World Bank’s Development Indicators (WDI).

Data for geographical distances, colonisation and shared official language and contiguity is taken from CEPIT’s GeoDist dataset.

For data related to each bilateral FTA, SAFTA and AIFTA the name, the date of entry into force, the original signatories, and specific entry or exit dates for additional signatories is taken from WTO Data set.

The ID_{ijt} variable for the Institutional Distance is derived from indicators of institutions from World Bank database which provides the data for six indicators of governance for each country since 1996 and each indicator takes the value lying between -2.5 and 2.5 . The institutional distance is computed as following:

$$ID_{ijt} = \frac{1}{6} \sum_{k=1}^6 \frac{(I_{ikt} - I_{jkt})^2}{V_{kt}}, \quad (11)$$

where I_{ikt} and I_{jkt} represent score of K^{th} institutional indicators for country i (India) and country j respectively in time t and V_{kt} is the variance of K^{th} institutional indicators across countries in time t .

CD_{ij} is the cultural distance variable, it is derived from Hofstede cultural indexes. Geert Hofstede provides data on six cultural indexes for a multitude of countries, the score for each index ranges from 0 to 100. It is computed as following:

$$CD_{ij} = \frac{1}{6} \sum_{k=1}^6 \frac{(C_{ik} - C_{jk})^2}{V_k}, \quad (12)$$

where C_{ik} and C_{jk} represent K^{th} cultural index for country i (India) and country j respectively and V_k is the variance of K^{th} cultural index across countries.

3.1 Estimation of stochastic frontier gravity model for exports and imports

Before presenting the results, it is pertinent to mention whether the model specification in the form of Stochastic Frontier Gravity model is required for the analysis of the data set used in this study, for which Log Likelihood Ratio Test is conducted. The Log Likelihood Ratio Test for Export inefficiency tests Null Hypothesis (H_0) of presence of no inefficiency against the Alternative Hypothesis (H_1) of presence of trade inefficiency. Since, in the present model there are 5 parameters for inefficiency model to be estimated, therefore the degrees of freedom for the test will be 5. The null hypothesis (H_0) of no inefficiency for the export model is rejected as the test statistic of the export model is 1450.8448, which is greater than the critical value of the test statistic given in Table 1, Kodde and Palm (1986) at the 1% level of significance and 5 degrees of freedom. Similarly, The LRR test for imports rejects the null hypothesis (H_0) of no import inefficiency with the test statistic of the model 1 795.6406 which is greater than the critical value given in Table 1, Kodde and Palm (1986) at 5 degrees of freedom and 1% level of significance.

Table 1 Estimation of stochastic frontier gravity model		
	(1) Inexports	(2) Inimports
<i>Frontier</i> <i>lnGDP_i</i>	0.717*** (14.65)	0.933*** (13.67)
<i>lnGDP_j</i>	0.573*** (25.95)	0.566*** (16.11)
<i>Indist</i>	-0.949*** (-14.33)	-0.436*** (-4.48)
<i>contig</i>	-0.154 (-1.20)	0.349* (2.08)
<i>comlang_off</i>	0.291*** (4.28)	-0.236* (-2.39)
<i>comcol</i>	0.824*** (10.12)	0.817*** (6.19)
<i>_cons</i>	-5.583*** (-4.04)	-15.22*** (-7.76)
<i>Mu</i> <i>Bilateral_FTA</i>	-10.44*** (-3.83)	-3.549*** (-3.54)
<i>AIFTA</i>	-2.491* (-1.98)	-1.035 (-1.12)
<i>SAFTA</i>	4.734*** (5.24)	5.356*** (4.71)
<i>CD</i>	1.436* (2.46)	0.886 (1.76)
<i>ID</i>	-4.854*** (-4.13)	-2.599* (-2.47)
<i>Usigma</i> <i>_cons</i>	0.606* (2.28)	0.966*** (3.85)
<i>Vsigma</i> <i>_cons</i>	-1.373*** (-17.21)	-1.083*** (-5.92)
<i>N</i>	529	529

Note: z statistics in parentheses $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
 Source: Authors calculation using Stata 17

In Table 1 the coefficients on $\ln(\text{GDP's})$ are positive and significant for both exports (model 1) and imports (model 2), implying that a proportional increase in GDPs of India and its trading partners has led to an increase in Indian exports and imports over the time period 2000–2022. The coefficient of $\ln(\text{distance})$ is negative and significant for both the models, indicating that distance has an inverse effect on exports and imports. These findings are consistent with the gravity literature. Among the other traditional gravity variables Contiguity is insignificant for India's exports, therefore does not impact India's exports significantly. However, contiguity has a positive and significant impact on India's imports which indicates that India imports more from the trading partners which are geographically located around India. Common_Lang_Off is positive and significant for India's exports and negative but significant for India's imports, which indicates that India exports less to the countries sharing the same official language with India while at the same time imports more from such countries these results are validated by Kumar and Prabhakar (2017). The comcol variable is positive and significant for both imports and exports indicating that India's trade (both exports and imports) is more with such countries that have shared the common coloniser with India in the past.

The inefficiency Formula (9) which is taken to be a function of FTA variables, Bilateral_FTA, AIFTA, SAFTA and the Institutional variables, ID and CD shows all the variables are significant determinants of export efficiency/inefficiency but only Bilateral_FTA, SAFTA and ID are significant determinants of import efficiency/inefficiency. The above model is used to derive export and import efficiency t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. of India. To find the impact of each determinant of efficiency a dynamic model specified in equation (10) is estimated separately. The marginal effects of the static model are given in the Appendix 3 in Tables A3.1 and A3.2.

3.2 Efficiency estimates

The estimated parameters of Stochastic Frontier Gravity Model are used to compute Mean export efficiency and mean import efficiency of India. Export/Import efficiency can be defined as realised export/import potential. The following tables provides the Mean efficiency of India's exports.

Table 2 Average export efficiency

Variable	Obs.	Mean	Std. dev.	Min.	Max.
Export efficiency	529	.756	.195	.007	.951

Source: Authors calculation using Stata 17

Table 3 Average import efficiency

Variable	Obs.	Mean	Std. dev.	Min.	Max.
Import efficiency	529	.569	.241	.000	.874

Source: Authors calculation using Stata 17

It can be seen from the Tables 2 and 3 that the mean value of export efficiency and import efficiency is approximately 0.76 and 0.57 respectively, implying that on average, India has realised approximately 76% of its export potential and 57% of import potential over the period 2000–2022.

3.3 The system GMM estimation of dynamic efficiency models

Before presenting the system GMM estimation of Formula (10) we conducted fisher's unit root test for ID-variable (it being the only non-dummy time variant variable). The test rejects the null

that all panels contain unit root at 1percent level of significance. For our post estimation check-ups about the validity of instruments we implement Hansen (1982) test and for post estimation check-up of no second order serial correlation (AR2) we implement Arellano-Bond test. The Hansen test does not reject the null hypothesis for either export efficiency model or import efficiency model. The Arellano-Bond test indicates the presence of first order autocorrelation (AR1) for both the models but rejects the presence of second order serial correlation (AR2) in any of the two models.

Table 4 System GMM estimation of export and import efficiency models

	Expeff		Impeff
<i>L.expeff</i>	0.801*** (30.07)	<i>L.impeff</i>	0.864*** (21.57)
<i>Bilateral_FTA</i>	0.060** (3.61)	<i>Bilateral_FTA</i>	0.130** (2.92)
<i>AIFTA</i>	-0.002 (-0.13)	<i>AIFTA</i>	-0.030 (-1.43)
<i>SAFTA</i>	-0.048** (-3.43)	<i>SAFTA</i>	-0.238*** (-5.49)
<i>CD</i>	0.100*** (10.21)	<i>CD</i>	0.020 (1.77)
<i>ID</i>	-0.002 (-0.36)	<i>ID</i>	0.021*** (4.50)
<i>N</i>	480	<i>N</i>	480

Note: t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Source: Authors calculation using Stata 17

Table 4 indicates that the variable (denoted by *L.expeff* and *L.impeff* in Table 4) is significant and exhibits a positive coefficient for both export and import efficiency. This suggests that trade efficiency from the previous year positively influences the current year's trade efficiency. These findings align with the research conducted by Antimiani and Costantini (2013) and Nguyen et al. (2023). A plausible explanation for this trend is that as two countries initiate trade, they gradually reduce formal trade barriers, leading to an incremental increase in trade efficiency over time.

Among the three types of Free Trade Agreements (FTAs) involving India, bilateral FTAs demonstrate a significant and positive correlation with India's import and export efficiency, indicating that these agreements enhance India's trade efficiency. Conversely, the ASEAN-India FTA appears to be insignificant concerning both export and import efficiency, corroborating the conclusions of Bhattacharyya and Mandal (2014) who assert that AIFTA lacks significance for most industries. Additionally, Ratna and Kallummal (2013) highlight that India incurs a welfare loss due to allocative inefficiency and adverse terms of trade effects under its FTA with ASEAN countries.

In contrast, the South Asian Free Trade Area (SAFTA) shows a negative and significant impact on both India's export and import efficiency, suggesting that SAFTA acts as a detriment to India's trade efficiency. This adverse effect may be attributed to conflicts of interest among SAFTA members, as noted by Joseph (2014), along with a higher prevalence of informal trade compared to formal trade within this group, as discussed by Akram et al. (2014).

The two institutional variables, Cultural Distance (CD) and Institutional Distance (ID), present mixed results in the existing literature. The CD variable is positively correlated and significant for India's export efficiency, yet it is insignificant for import efficiency in this study. This indicates that cultural dissimilarities

between India and its trading partners positively influence export efficiency, while having no significant effect on import efficiency. Conversely, the ID variable, which pertains to governance dissimilarity, shows a positive and significant effect on India's import efficiency, but remains insignificant for export efficiency.

CONCLUSION

This study examines the role of FTAs and institutions in determining India's export potential and India's import potential. The paper includes the data from India and 45 countries from 2000–2022. The estimation shows that India realises 76% of its export potential and 57% of its import potential. The results for FTAs are such that bilateral FTAs of India are trade efficiency enhancing and therefore it is suggested to liberalize the trade through bilateral FTAs. The SAFTA has adverse effects on both export efficiency as well as import efficiency of India, this is due to the prevalence of informal trade and conflict of interest among SAFTA members, hence such bottlenecks must be removed to increase the efficiency of trade. The India-ASEAN FTA is found to be insignificant for either of India's export efficiency as well as India's import efficiency, this is due the factors other than tariffs as pointed out by Bhattacharya and Mundal (2014). It is suggested that such factors be identified and their effect on trade be reduced to increase the trade efficiency of India and its ASEAN members.

Among the institutional variables CD representing the cultural-distance between India and each of its trading partners, has a positive effect on export efficiency and insignificant effect on import efficiency. While ID representing the distance in the governance structures of India and each of its trading partners, has a positive effect on import efficiency and an insignificant effect on India's export efficiency. The effects of these two Institutional distances on trade in general and trade efficiency in particular is not uniform or of the same direction for all the countries in all the cases as is mentioned in the section of literature review on Institutional-distance and Trade (Section 1.2). The possible reason for such an inconclusive phenomenon is that while the magnitude of both CD and ID is directly related to the costs of transaction between any two trading partners, the two variables also impact the flow of foreign investments between the trading countries. When the two countries are less distant institutionally there is an increase in the flow of foreign investments between them, which impacts the flow of trade between two such countries in a negative way and vice-versa. Since it is a gradual and long-term process to change the institutions and policymakers have a limited effect on institutions in the short term. Therefore, it is suggested that India must look for more exports to culturally distant countries and increase its imports from such countries that have differing governance structures to that of India.

The limitations of this study are that the number of India's trading partners does not include all the countries. Secondly, we do not include sector-specific effects of FTAs and institutions in the study. Due to the uniqueness of each industry FTAs and institutions do not have same effects across all the sectors of the economy. These two gaps form the potential topics for the future research.

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APPENDIX 1

Table A1 List of India's trade partners included in the study

Afghanistan	Italy	Saudi Arabia
Australia	Japan	Singapore
Bangladesh	Lao PDR	South Africa
Belgium	Malaysia	Sri Lanka
Bhutan	Maldives	Tanzania Thailand
Brazil	Mauritius	UAE
Brunei Darussalam	Myanmar	UK
Cambodia	Nepal	USA
Chile	Netherlands	Vietnam
China	Oman	
Hong Kong SAR	Pakistan	
France	Philippines	
Germany	South Korea	
Indonesia	Russia Federation	

Source: WTO

APPENDIX 2

Table A2 Institutional indicators considered in the study

Governance institutions	Cultural institutions
1. Control of corruption	1. Individualism and collectivism
2. Rule of law	2. Power distance
3. Regulatory quality	3. Masculinity and femininity
4. Government effectiveness	4. Uncertainty avoidance
5. Political stability and absence of violence	5. Long-term orientation
6. Voice and accountability	6. Indulgence

Source: Worldwide governance indicators by World Bank and the 6-D model of national culture of Geert Hofstede

APPENDIX 3

According to Kumbhakar, Subal, and Horncastle (2015) maximum likelihood estimates of the inefficiency equation may not be very relevant for empirical purposes. The marginal effect of each determinant of inefficiency determines the magnitude of that determinant. Furthermore, Wang (2002) suggests that determinants of inefficiency do not have to be positive or negative for every observation. Therefore, marginal effects for the static model are also calculated.

Marginal effects of the static models

When the change in the level of inefficiency/efficiency is estimated due to the change in level of determinants of inefficiency/efficiency, we get Marginal effects of inefficiency/efficiency The marginal effects of each

inefficiency/efficiency determinant show how much, on average, a change in the level of each inefficiency/efficiency determinant leads to a change in the expected value of inefficiency/efficiency. The following tables give the marginal inefficiency for exports and imports respectively.

Table A3.1 Marginal effects on export inefficiency

Variables	Obs.	Mean	Std. dev	Min.	Max.
<i>Bilateral ~ M</i>	529	-1.018	1.849	-10.360	-.017
<i>AIFTA_M</i>	529	-.243	.441	-2.472	-.004
<i>SAFTA_M</i>	529	.461	.838	.008	4.696
<i>CD_M</i>	529	.140	.254	.002	.425
<i>ID_M</i>	529	-.316	.837	-4.804	.034

Source: Authors calculation using Stata 17

Table A3.2 Marginal effects on import inefficiency

Variables	Obs.	Mean	Std. dev	Min.	Max.
<i>Bilateral ~ M</i>	529	-.715	.795	-3.526	-.038
<i>SAFTA_M</i>	529	1.080	1.199	.057	5.321
<i>ID_M</i>	529	.085	.607	-2.563	.205

Source: Authors calculation using Stata 17

The positive values for determinant of marginal inefficiency indicate an on average increase in marginal inefficiency due to that determinant of inefficiency and the negative values indicate an on average decrease in the inefficiency due to that determinant. Table A3.1 gives the marginal effects on export inefficiency it can be seen from the table that *Bilateral_FTAs*, *AIFTA* and *ID* are negative therefore inefficiency decreasing factors while *SAFTA* and *CD* are positive and therefore inefficiency enhancing factors. The marginal contribution of *Bilateral_FTAs* is highest amounting to 102% approximately followed by *ID* which amounts to 32% approximately and *AIFTA* which is 24% approximately among the inefficiency decreasing factors. Among the inefficiency enhancing factors marginal contribution of *SAFTA* is 46% approximately and that of *CD* is 14% approximately.

Table A3.2 gives the marginal effects on import inefficiency, in the table it can be seen *Bilateral_FTAs* and *ID* are negative therefore inefficiency decreasing factors, these two on average contribute 71% and 8%, respectively, in decreasing import inefficiency. While, marginal effect of *SAFTA*, is import inefficiency enhancing by approximately 107%. The *AIFTA* and *CD* are insignificant for import inefficiency/efficiency.

Modelling Financial Crises Linked to Foreign Exchange Regime Transitions: the Case of Morocco

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Abstract

This study simulates financial crises within Morocco's exchange rate market using over 15 years of quarterly data. A Structural Vector Autoregressive (SVAR) model is developed to analyse key economic variables influencing Morocco's forex dynamics. The paper outlines four distinct crisis scenarios related to the exchange rate liberalisation process, explicitly considering the impacts of the COVID-19 pandemic. The simulations reveal critical insights that can assist academics and economic stakeholders effectively manage the risks associated with exchange rate transitions and global financial crises in developing countries. The findings emphasise the importance of tailored policy responses and risk management strategies, which are crucial for similar economies facing vulnerabilities in their foreign exchange markets. Additionally, this research offers a framework that can be adapted to analyse the economic dynamics of other developing nations, enhancing their ability to navigate periods of economic turbulence and fostering resilience against future financial shocks.

Keywords

COVID-19, flexibilization, crisis simulation, exchange rate, Morocco

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INTRODUCTION

An economic crisis is typically defined by a substantial contraction in a nation's financial performance, often triggered by disruptions in key economic factors, such as monetary aggregates, which influence

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supply and demand dynamics. The recurrence of such crises over the past two decades has driven researchers to refine forecasting and simulation models to predict their impacts and devise effective mitigation strategies. Literature underscores the crises' multifaceted and interconnected nature, wherein various economic components interact. Reinhart and Rogoff (2009) highlight the historical recurrence of financial crises, suggesting that insights drawn from past events can guide contemporary policy decisions. Krugman (1999) emphasises the pivotal role of exchange rate mechanisms in preserving economic stability, particularly during financial turbulence, while Mishkin (1991) explores how monetary policy frameworks shape crisis dynamics.

Crisis simulation studies are often classified into two primary approaches. The first focuses on stress tests or extreme shock scenarios, such as those conducted by Alfaro and Drehmann (2009), who assess vulnerabilities in the banking sector, Smeral (2010), who evaluates shocks to tourism demand, and the ESRB (2016), which investigates systemic risks within European financial markets. The second approach employs econometric models that integrate various economic components. For instance, Li et al. (2021) apply a structural vector autoregression framework to analyse economic interactions, while Tamási and Világi (2011) concentrate on macroeconomic modelling, and Haug et al. (2013) examine the dynamic interdependencies among economic variables, shedding light on the complexity of these relationships.

Despite these advancements, the COVID-19 pandemic has exposed the limitations of traditional models, which often fail to account for the full scope of global crises. Baldwin and Tomiura (2020) argue for the need of adaptive frameworks capable to address the distinctive challenges of such unprecedented events. Sun et al. (2023) illustrate how the COVID-19 pandemic disrupted labour markets, complicating crisis management strategies due to shifts in employment and income distribution.

Within the Moroccan context, limited research has been conducted on simulating crises and shocks. Bakkou (2014) explores the economic impacts of rainfall-related shocks, while Bahaddi et al. (2017) examine the effects of fiscal shocks on national financial stability. Tahriand Karim (2018) and Ouchchikh (2017) investigate the consequences of monetary and fiscal policy shocks, stressing the need for comprehensive frameworks to address these challenges. Additionally, studies such as those by Ramey (2011) underscore the importance of structural models in understanding the transmission of shocks across economies, offering more profound insights into policy responses.

This paper proposes a synthetic approach to crisis simulation within the Moroccan foreign exchange market, utilising a Structural Vector Autoregressive (SVAR) model alongside various crisis scenarios. This methodology seeks to address the gap in the literature regarding the Moroccan economy's vulnerability to external shocks and crises, thereby enhancing the understanding of crisis dynamics. By offering a detailed analysis of the interactions between exchange rate fluctuations and macroeconomic variables, this study aims to equip policymakers and economic stakeholders with the tools to develop effective contingency plans for future crises. The findings are expected to provide valuable insights into managing risks associated with exchange rate fluctuations and global financial crises, particularly concerning Morocco's ongoing liberalisation process.

The article is structured as follows: Section 1 introduces the topic and outlines the research objectives. Section 2 presents the data and theoretical framework. Section 3 describes the empirical methodology. Section 4 discusses the results and their implications. Last section concludes with policy recommendations and suggestions for future research.

1 MODEL DATA

1.1 Presentation

The Moroccan foreign exchange market operates within a regulated framework, closely monitored by the country's monetary authorities. This regulatory environment requires the inclusion of variables that reflect the central bank interventions to model exchange rate dynamics accurately. Bouhali et al. (2022)

highlighted that central bank actions significantly influence exchange rate movements. In Morocco, as in other developing markets like Tunisia and Kenya, improving competitiveness and stabilising the current account balance are key goals in transitioning to more flexible exchange rate regimes. Agbeyegbe et al. (2006) underscore the importance of trade policy adjustments in influencing exchange rates, further justifying the inclusion of such variables in our model.

We have selected key variables aligning with the Moroccan economic context and theoretical insights from the literature. The first variable, the exchange rate (FX_RATE), is central to simulating exchange rate crises due to its critical role in maintaining macroeconomic balance. Exchange rate fluctuations can significantly affect inflation, trade, and overall economic stability (Reinhart and Rogoff, 2009). The second one, misalignment (MIS), which measures the deviation between the nominal and real value of the local currency, provides insight into inflationary pressures and the competitiveness of exports. According to Gros (1997), exchange rate misalignments are often associated with trade imbalances and economic instability, making it a crucial factor in modelling crisis scenarios.

The third variable, foreign exchange reserves (RES), is essential for the central bank's ability to intervene in the foreign exchange market, particularly under Morocco's managed exchange rate system. As Mishkin (1991) emphasised, a country's reserves play a critical role in stabilising the exchange rate during periods of volatility or external shocks. Morocco's reliance on external sources, particularly energy and food, makes the fourth variable, balance of trade (BoT), essential for modelling economic stability. A substantial trade deficit can lead to external vulnerabilities, as highlighted by Krugman (1999), which is why the trade balance is vital for Morocco's economic health and the stability of its currency.

The central bank interest rate (BAM_IR) is vital for guiding monetary policy, controlling inflation, and stabilising the exchange rate. As illustrated by Mishkin (1991), interest rates are a key tool for managing economic activity and influencing currency stability. The central bank's rate directly impacts Morocco's inflation and exchange rate expectations. Lastly, fiduciary money (FIAT), representing the money supply, is crucial in Morocco's cash-based economy. According to Gros (1997), fluctuations in the money supply can significantly affect inflation, interest rates, and exchange rates, making it an essential variable for understanding economic dynamics.

Table 1 outlines the key variables in this model, which are essential for understanding Morocco's foreign exchange market and macroeconomic conditions. These variables enable a thorough analysis of Morocco's economic vulnerabilities, especially during exchange rate regime transitions, and provide a transparent, replicable framework for future research.

Table 1 List of variables used in the SVAR model

Frequency	Variable	Source	Unit	Description
Quarterly data from Q1 2003 to Q4 2019	FX_RATE	IMF	Without unit	Average nominal exchange rate for the quarter
	MIS		Percentage	Exchange rate misalignment
	RES		USD	Official foreign exchange reserves
	BoT		USD	Trade balance
	BAM_IR		Percentage	Bank Al-Maghrib (Moroccan Central Bank) key interest rate
	FIAT		MAD	Fiduciary money: banknotes and coins in circulation

Source: Compiled by authors

1.2 Stationarity

The variables must be stationary at the first level to ensure their suitability for the VAR model. Table 2 presents the results of the Augmented Dickey-Fuller (ADF) test, showing that all variables are stationary at the first level, making them appropriate for inclusion in the model.

Table 2 ADF Test results for SVAR variables

Variable		Level	1 st difference
USD/MAD	ADF statistics	-1.86	-6.16
	P-value (level)	0.34	0.00
MIS	ADF statistics	0.01	-7.61
	P-value (level)	0.95	0.00
RES	ADF statistics	-2.33	-7.11
	P-value (level)	0.16	0.00
BOT	ADF statistics	-2.12	-4.03
	P-value (level)	0.23	0.00
BAM_IR	ADF statistics	0.10	-6.70
	P-value (level)	0.96	0.00
FIAT	ADF statistics	0.34	-9.06
	P-value (level)	0.97	0.00

Source: Computed by authors, EVIEWS

2 THEORETICAL FRAMEWORK

2.1 VAR model

The Vector Autoregressive (VAR) model is widely used to analyse interdependent time-series systems, allowing for examining unexpected shocks across multiple variables. In its reduced form, each endogenous variable is expressed as a function of the lagged values of all other endogenous variables. The stationary, k-dimensional VAR(p) process can be written as:

$$y_t = A_1 y_{t-1} + A_p y_{t-p} + Cx_t + \varepsilon_t, \tag{1}$$

where:

- $y_t = (y_{1t}, y_{2t}, \dots, y_{kt})'$ is a $k \times 1$ vector of endogenous variables,
- $x_t = (x_{1t}, x_{2t}, \dots, x_{dt})'$ is a $d \times 1$ vector of endogenous variables,
- A_1, \dots, A_p a $k \times k$ matrices of coefficients associated with the lags of the endogenous variables,
- C is a $k \times d$ matrix of coefficients for the exogenous variables,
- $\varepsilon_t = (\varepsilon_{1t}, \varepsilon_{2t}, \dots, \varepsilon_{dt})'$ is a $k \times 1$ vector of innovations (white noise), with $E(\varepsilon_t) = 0$, $E(\varepsilon_t \varepsilon_t') = \Sigma_\varepsilon$ and $E(\varepsilon_t \varepsilon_s') = 0$ for $t \neq s$.

The innovations are contemporaneously correlated through the covariance matrix Σ_ε but uncorrelated across periods. The model can be compactly expressed in matrix form as:

$$Y = BZ + E, \tag{2}$$

where:

$Y = (y_1, y_2, \dots, y_T)$ and $E = (\varepsilon_1, \varepsilon_2, \dots, \varepsilon_T)$ are $k \times T$ matrices of endogenous variables and innovations, respectively,

$B = (A_1, A_2, \dots, A_p, C)$ is a $k \times (pk + d)$ matrix of coefficients,

$Z = (Z_1, Z_2, \dots, Z_T)$ is a $(pk + d) \times T$ matrix of the lagged endogenous and exogenous variables.

Ordinary least squares (OLS) can provide consistent estimates of the coefficients, assuming the innovations are uncorrelated with the regressors.

2.2 SVAR model

The Structural Vector Autoregressive (SVAR) model extends the VAR framework by imposing additional identification restrictions. These restrictions, typically based on economic theory or assumptions about the contemporaneous relationships among variables, add complexity to the model and enhance its predictive power. This predictive power is particularly beneficial for policymakers, as it allows them to anticipate the potential impact of economic shocks and take proactive measures to mitigate their effects. The SVAR model transforms the reduced-form errors into uncorrelated structural shocks, essential for impulse response analysis, forecast variance decomposition, and causal inference.

The SVAR model can be expressed as:

$$Ay_t = A_1^s y_{t-1} + \dots + A_p^s y_{t-p} + C^s x_t + Bu_t, \quad (3)$$

where:

(A_1^s, \dots, A_p^s) and C^s represent the structural coefficients,

u_t denotes the unobserved orthonormal structural innovations with $E(u_t, u_t') = I_k$.

Assuming A is invertible, it can be rewritten in reduced form as:

$$y_t = A^{-1}A_1^s y_{t-1} + \dots + A^{-1}A_p^s y_{t-p} + A^{-1}C^s x_t + A^{-1}Bu_t. \quad (4)$$

The reduced-form errors ε_t are related to the structural shocks u_t By:

$$\varepsilon_t = A^{-1}Bu_t = Su_t, \quad (5)$$

where: $S = A^{-1}B$. The covariance matrix of the reduced-form errors is:

$$\Sigma_\varepsilon = A^{-1}BB'(A^{-1})' = SS'. \quad (6)$$

The identification of the SVAR model requires additional restrictions on the matrices. A and B as there are more parameters to estimate than available moments in Σ_ε . These restrictions are typically based on economic theory or assumptions about the contemporaneous relationships among variables.

2.3 Application of the models

The VAR and SVAR models, when applied in this study, provide a comprehensive analysis of the dynamics of Morocco's foreign exchange market and simulate crisis scenarios. The VAR model captures interdependencies among key macroeconomic variables, such as the exchange rate, foreign reserves, trade balance, and policy rates, allowing us to examine how shocks propagate through the system. The SVAR model, however, extends this analysis by imposing structural restrictions to identify underlying economic shocks. This enables us to simulate crisis scenarios, conduct impulse response analysis, and perform variance decomposition. Notably, the SVAR model offers valuable insights into

the transmission mechanisms of financial crises, providing policymakers with crucial guidance on managing risks associated with exchange rate transitions and global economic turbulence.

3 EMPIRICAL RESULTS

3.1 Model estimation

The SVAR model was estimated in two stages: first, using ordinary least squares (OLS) to assess the VAR model, followed by applying structural constraints to calculate the A and B matrix coefficients. The model identifies key relationships between the exchange rate, policy rate, foreign exchange reserves, and macroeconomic variables, providing insights into Morocco's foreign exchange market. The results of the VAR model are presented in Formulas (7)–(12):

$$\begin{aligned} USDMAT = & 0.93 \times USDMAT(-1) - 0.48 \times USDMAT(-2) - 0.32 \times MIS(-1) + 0.87 \times MIS(-2) \\ & - 6.21e - 05 \times RES(-1) + 3.94e - 05 \times RES(-2) + 7.75e - 05 \times BOT(-1) + 5.71e - 05 \times BOT(-2) \\ & - 0.73 \times BAM_{IR(-1)} - 0.01 \times BAM_{IR(-2)} - 2.64e - 06 \times FIAT(-1) + 1.43e - 06 \times FIAT(-2) \\ & + 8.14, \end{aligned} \quad (7)$$

$$\begin{aligned} MIS = & - 0.003 \times USDMA(-1) + 0.001 \times USDMA(-2) + 0.90 \times MIS(-1) + 0.019 \times MIS(-2) \\ & - 1.61e - 07 \times RES(-1) + 8.56e - 09 \times RES(-2) - 1.13e - 08 \times BOT(-1) + 1.54e - 07 \times BOT(-2) \\ & + 0.002 \times BAM_{IR(-1)} - 0.002 \times BAM_{IR(-2)} - 1.53e - 07 \times FIAT(-1) + 5.28e - 07 \times FIAT(-2) \\ & + 0.001, \end{aligned} \quad (8)$$

$$\begin{aligned} RES = & - 230.71 \times USDMA(-1) + 1143.18 \times USDMA(-2) + 8297.39 \times MIS(-1) \\ & + 16949.13 \times MIS(-2) + 0.91 \times RES(-1) + 0.10 \times RES(-2) + 0.27 \times BOT(-1) + 0.31 \times BOT(-2) \\ & + 4545.26 \times BAM_{IR(-1)} - 2698.37 \times BAM_{IR(-2)} - 0.093 \times FIAT(-1) + 0.061 \times FIAT(-2) \\ & - 10894.69, \end{aligned} \quad (9)$$

$$\begin{aligned} BOT = & 774.93 \times USDMA(-1) - 253.60 \times USDMA(-2) - 1.91 \times MIS(-1) \\ & - 1.06 \times MIS(-2) + 7.20e - 06 \times RES(-1) - 1.66e - 05 \times RES(-2) - 0.04 \times BOT(-1) + 0.46 \times \\ & BOT(-2) + 763.37 \times BAM_{IR(-1)} - 828.87 \times BAM_{IR(-2)} + 0.004 \times FIAT(-1) - 0.01 \times FIAT(-2) \\ & - 4386.77, \end{aligned} \quad (10)$$

$$\begin{aligned} BAM_{IR} = & - 0.06 \times USDMA(-1) - 0.018 \times USDMA(-2) - 1.91 \times MIS(-1) - 1.06 \times MIS(-2) \\ & + 7.20e - 06 \times RES(-1) - 1.66e - 05 \times RES(-2) - 2.55e - 05 \times BOT(-1) - 1.64e - 05 \times BOT(-2) \\ & + 0.88 \times BAM_{IR(-1)} - 0.19 \times BAM_{IR(-2)} - 5.70e - 06 \times FIAT(-1) + 8.14e - 06 \times FIAT(-2) \\ & + 1.64, \end{aligned} \quad (11)$$

$$\begin{aligned} FIAT = & - 359.93 \times USDMA(-1) + 935.25 \times USDMA(-2) + 92319.97 \times MIS(-1) \\ & - 73345.68 \times MIS(-2) + 0.36 \times RES(-1) - 0.13 \times RES(-2) + 0.54 \times BOT(-1) - 0.66 \times BOT(-2) \\ & + 2723.89 \times BAM_{IR(-1)} - 4882.94 \times BAM_{IR(-2)} + 0.75 \times FIAT(-1) + 0.09 \times FIAT(-2) \\ & + 3598.81. \end{aligned} \quad (12)$$

The second step involves identifying the structural constraint matrices A and B, as shown in Tables 3 and 4. At least 21 elements of these matrices must be determined to satisfy the rank condition. The six diagonal elements of matrix A are trivially identified and set to 1, reflecting that the movement of a variable affects its evolution within the same period. The remaining structural constraints and the rationale for their selection are detailed in the Appendix.

Table 3 Structural constraints matrix A

	USD/MAD	MIS	RES	BOT	BAM_IR	FIAT
USD/MAD	1	0	0	C3	0	0
MIS	C1	1	0	0	0	0
RES	0	0	1	C4	0	0
BOT	C2	0	0	1	0	0
BAM_IR	0	0	0	0	1	0
FIAT	0	0	0	C5	0	1

Source: Computed by authors, EViews

Table 4 Structural constraints matrix B

	USD/MAD	MIS	RES	BOT	BAM_IR	FIAT
USD/MAD	C6	0	C11	0	C16	0
MIS	0	C9	0	0	C17	0
RES	C7	0	C12	0	0	0
BOT	0	C10	C13	C14	0	0
BAM_IR	C8	0	0	C15	C18	0
FIAT	0	0	0	0	C19	C20

Source: Computed by authors, EViews

Residual diagnostic tests confirmed the model's validity and reliability, including autocorrelation, normality, and heteroscedasticity. The next step is to analyse the impulse responses and perform variance decomposition.

3.2 Impulse responses

When exposed to shocks, the impulse response analysis uncovers the dynamic relationships among Morocco's macroeconomic variables. A shock to the USD/MAD exchange rate initially results in a depreciation of the Dirham, which is followed by a sharp appreciation from the third quarter onward, aligning with the 'overshooting' theory proposed by Dornbusch (1976). This theory suggests that exchange rates may initially move more than necessary in response to a shock and then gradually return to a new equilibrium. Likewise, misalignment shocks (discrepancies between nominal and real exchange rates) induce short-term depreciation, reflecting adjustments in export competitiveness, as outlined by Krugman (1999). These patterns echo the vulnerability of emerging markets to abrupt changes in investor sentiment, a phenomenon widely discussed by Reinhart and Rogoff (2009). Foreign reserves increase during currency depreciation, consistent with central bank interventions in managed exchange rate regimes (Agbeyegbe et al., 2006), but sharply decline following direct shocks, illustrating fragility during extended crises. Simultaneously, the policy rate decreases persistently after exchange rate and misalignment shocks, reflecting Mishkin's (1991) finding that central banks prioritise economic growth over inflation control during periods of turbulence.

The trade balance improves following misalignment shocks, as a weaker local currency enhances export competitiveness (a concept central to open-economy models by Krugman, 1999), but worsens after reserve or policy rate shocks due to imported inflation and reduced demand. Liquidity dynamics reveal behavioural shifts: the number of banknotes in circulation falls significantly after currency shocks, likely driven by hoarding behaviours in cash-dependent economies (Bouhali et al., 2022), while trade balance shocks increase liquidity from the third quarter onward, suggesting delayed fiscal responses. The J-shaped curve of misalignment after currency shocks and the ongoing policy rate decline after trade balance shocks highlight the intricate interdependencies within Morocco's economy, which aligns with Haug et al. (2013)'s focus on spillover effects in small open economies. Drawing on Baldwin and Tomiura's (2020) analysis during the COVID-19 crisis, adaptive frameworks are essential for Morocco. These frameworks involve flexible policies that can quickly adapt to changing economic conditions. Strategic reserve buffers, such as foreign exchange reserves, targeted monetary interventions, and export diversification policies, can strengthen resilience to global financial turbulence, providing a roadmap for policymakers to balance growth, stability, and competitiveness.

3.3 Variance decomposition

The variance decomposition analysis in Figure A3 in the Appendix unveils the dynamic interactions between key economic variables over the short and medium term. The increasing influence of the policy rate and trade balance on exchange rate movements sheds light on the factors shaping exchange rate volatility under Morocco's managed regime. Similarly, the substantial impact of the exchange rate on misalignment, coupled with the growing influence of fiduciary money in the medium term due to inflationary pressures, provides a deeper understanding of Morocco's economic dynamics and keeps the audience engaged.

The trade balance is significantly shaped by the exchange rate and misalignment, with reserves and the policy rate gaining importance in the medium term as tools for managing external and internal stability. The policy rate is increasingly influenced by the trade balance, exchange rate, and misalignment, reflecting its role in addressing imported inflation and volatility. Finally, fiduciary money, which refers to money not backed by a physical commodity like gold, is strongly tied to foreign exchange reserves, with growing contributions from the trade balance and misalignment in the medium term, underscoring the interplay between monetary policy and external trade. Figure A4 in the Appendix provides further historical decomposition insights, illustrating the temporal evolution of these relationships.

Several parallels and distinctions emerge when compared to findings in the literature for countries with monetary unions or currency board regimes. In monetary unions, such as the Eurozone, the exchange rate is often less volatile due to the shared currency, reducing the direct influence of individual member states' policy rates and trade balances on exchange rate dynamics. However, similarly to Morocco's case, external imbalances and misalignment remain critical factors affecting competitiveness and stability, as highlighted by De Grauwe (2016). In contrast, countries with currency-board regimes, such as Bulgaria or Hong Kong, rely more on foreign exchange reserves to maintain fixed exchange rates, mirroring Morocco's use of reserves to stabilise its managed regime – studies by Ghosh et al. (2016) on currency boards emphasise the importance of reserves in mitigating external shocks, a finding consistent with our results.

That said, unlike currency-board regimes, where the fixed exchange rate entirely constrains monetary policy, Morocco's managed float allows for greater flexibility in using the policy rate to address domestic inflationary pressures and external imbalances. This flexibility aligns more closely with countries' experiences in monetary unions, where national central banks retain some autonomy in addressing asymmetric shocks. For instance, the European Central Bank's monetary policy often balances the needs

of individual member states with divergent economic conditions, similar to how Morocco's central bank navigates domestic and external trade-offs.

The analysis underscores the interconnectivity of these variables, highlighting the need for coordinated monetary and exchange rate policies, particularly in Morocco's managed exchange rate regime. These findings offer valuable insights for policymakers and suggest avenues for future research, especially in comparing the experiences of emerging economies with those of countries in monetary unions or currency board regimes.

3.4 Crisis simulation

The impulse response analysis provides valuable insights into the model's behaviour in response to individual shocks. However, crises are often characterised by multiple simultaneous shocks that affect various macroeconomic variables. We propose crisis scenarios involving complex, concurrent shocks over time to address this limitation. These scenarios help capture the cumulative effects of several shocks, illustrating their impacts on the model's components.

3.4.1 Currency crisis

This scenario simulates a currency crisis characterised by a swift and significant drop in the value of the national currency. The design of this scenario takes inspiration from Morocco's market dynamics, particularly the shift to a new exchange rate regime in January 2018. During this transition, the local currency depreciated by 2.5%, the maximum the central bank allowed. This depreciation continued due to the outflow of dividends to foreign investors during the second and third quarters of 2018, resulting in an additional 2.5% depreciation. By the first quarter of 2020, the central bank widened the exchange rate bands to 5% to address liquidity issues. This scenario helps capture the cumulative effects of several shocks, illustrating their impacts on the model's components.

The economic consequences of this crisis scenario are notable. The policy interest rate experiences a considerable drop from its projected value under normal conditions. This reduction is intended to stimulate the economy, which the rising cost of imports has negatively impacted. The central bank lowers interest rates to encourage investment and promote the substitution of imported goods with domestically produced ones, particularly those with lower to medium price elasticity, such as food and manufactured goods. As a result, the trade balance improves, driven by a decrease in imports after the depreciation, as Moroccan consumers begin favouring local products, which become more competitive. Additionally, the depreciation of the Dirham enhances the competitiveness of Moroccan exports, especially in regional markets, which further boosts the trade balance. However, this shift may contribute to inflation, mainly due to the high price sensitivity of certain imports like oil, medicine, and wheat.

Unexpectedly, the scenario also reveals an increase in reserves, which contradicts the typical expectation of reserve depletion during a currency crisis. This positive shift can be attributed to the central bank's decision not to intervene directly in the market and to expand the exchange rate bands, allowing the market to self-correct. This policy aligns with the Moroccan Central Bank's 2018 approach, which aimed to improve market flexibility without heavy reliance on foreign reserves. Furthermore, the impact on fiduciary currency and misalignment is minimal, with misalignment decreasing after the final depreciation, indicating that the nominal value of the Dirham is closely aligned with its actual economic value.

In the literature, currency crises are usually associated with the depletion of foreign reserves, followed by sharp depreciation. A well-known example is the 1994 Mexican Peso Crisis, which involved a significant currency devaluation, leading to inflation and a rapid drop in reserves (Calvo and Mendoza, 2000). Morocco's situation, however, diverges from this pattern as it experiences a surprising rise in reserves. This behaviour challenges the conventional view, as most countries undergoing currency crises, such

as Thailand in 1997, faced reserve depletion when attempting to defend their currency pegs (Radelet and Sachs, 1998).

The experience of countries with currency board arrangements, such as Argentina in the 1990s, highlights the vulnerabilities of rigid exchange rate systems. In Argentina's case, the currency board system prevented the central bank from adjusting interest rates or devaluing the currency, contributing to instability during the 2001 crisis (Alesina and Barro, 2002). In contrast, Morocco's approach, which allows for greater flexibility within its managed exchange rate system, provides an advantage in handling currency crises. This system offers more control over monetary policy compared to a currency-board system. Similarly, countries in monetary unions, like those in the Eurozone, face challenges in managing currency depreciation during times of crisis. For example, during the 2008 Global Financial Crisis, Greece, unable to devalue its currency due to its membership in the Eurozone, faced exacerbated fiscal and trade imbalances (Blanchard and Giavazzi, 2002). Morocco's ability to adjust exchange rate bands provides a strategic advantage over countries with more restricted flexibility.

3.4.2 Trade balance crisis

In this scenario, we assume that Morocco's trade balance worsened by 5% during the first quarter of 2017 following the announcement of a potential shift to a new exchange rate regime. This uncertainty triggers a market panic, leading to a contraction in trade balance figures. A further 5% decline is expected in Q1 2018 as the new exchange rate regime is implemented. By Q1 2019, a 10% decline is anticipated, driven by external economic pressures, such as rising import costs and a decrease in the competitiveness of Moroccan exports.

The economic effects of this trade balance crisis provide several key insights. The policy interest rate rises approximately two quarters after each deterioration in the trade balance. This increase aims to control domestic demand and promote the substitution of imports, thus stabilising the economy in response to external shocks. The central bank seeks to mitigate inflationary pressures typically associated with a deteriorating trade balance by raising the policy rate, providing a cushion against economic instability. Despite the decline in the trade balance, the Moroccan Dirham appreciates, contrary to the usual expectation that a worsening trade balance would lead to a depreciation due to increased demand for foreign currency. This unexpected appreciation is mainly due to Morocco's fixed exchange rate regime and strict capital controls, which enable the central bank to manage currency supply through foreign exchange reserves. Additionally, the rate hike and the relative strength of the Dirham help reduce inflationary expectations, contributing to the Dirham's appreciation.

There is minimal effect on currency misalignment, even with the Dirham's appreciation. This indicates that the Dirham remains closely aligned with its underlying value, supported by Morocco's monetary policy framework, which aids in maintaining currency stability during periods of external distress. The Dirham's appreciation in the face of a worsening trade balance contrasts with the experience of countries operating with a currency board arrangement, where a similar trade balance crisis would usually lead to currency depreciation. A relevant example is Estonia in the 1990s, where a fixed exchange rate system constrained the central bank's ability to adjust the currency in response to external shocks (Gros, 1997). However, Morocco's ability to change exchange rate bands provides it greater flexibility in managing trade imbalances and currency fluctuations.

Similarly, countries in monetary unions, like Spain during the 2008 financial crisis, faced difficulties managing trade balance crises. Spain's trade balance worsened, but its inability to devalue its currency as part of the Eurozone aggravated its economic struggles. The lack of exchange rate flexibility hindered Spain's ability to regain competitiveness in global markets. In contrast, Morocco's managed exchange rate regime allows it to adjust its exchange rates to manage trade imbalances better, highlighting the advantages of flexibility in managing economic crises.

3.4.3 Foreign exchange reserves crisis

This scenario centres on the decline in foreign exchange reserves, a crucial indicator of economic instability for countries with fixed exchange rate systems. In this case, we simulate a 5% decrease in reserves in Q1 2017, followed by further declines in Q3 2017, Q1 2018, and Q1 2019. Market reactions to uncertainties and changes in the exchange rate regime compound these declines.

The economic impacts of this scenario include a significant depreciation of the Dirham, triggered by a surge in demand for foreign currencies as market participants react to concerns about further declines in reserves. Local banks seek liquidity from the central bank, which responds by conducting Dutch-style tenders and auctions to ensure an adequate supply of foreign currency. This intervention intensifies the depreciation of the Dirham. As the currency weakens, importers reduce their import volumes and shift to domestic substitutes, improving the trade balance. Additionally, a significant decrease in the circulation of banknotes occurs as residents anticipate the need for cash for potential foreign travel, for example. However, exchange control measures help temper this decline by regulating foreign currency allocation. The policy interest rate adjusts J-shaped, initially falling before increasing after the second shock. This adjustment reflects the central bank's efforts to address the rising demand for foreign currency and stabilise the economy.

This scenario mirrors the experiences of countries with currency board systems, such as Argentina, during the 2001 crisis, where falling reserves and the inability to adjust the currency peg led to widespread economic instability (Calvo, 2006). In currency-board countries like Argentina, the central bank's failure to alter interest rates or devalue the currency often results in severe economic crises. Morocco's approach, which allows adjustments to its exchange rate bands, provides greater flexibility in managing such crises.

Similarly, countries in monetary unions, such as Greece during the Eurozone crisis, faced similar challenges related to foreign reserves and currency depreciation. During the crisis, Greece could not devalue its currency or adjust its monetary policy, which exacerbated its financial difficulties (Buiter and Grafe, 2002). Morocco's ability to widen its exchange rate bands offers a significant advantage in managing a reserves crisis compared to countries within monetary unions where such flexibility is unavailable.

3.4.4 COVID-19 economic crisis

In this scenario, we examine the impact of the COVID-19 pandemic on Morocco's economy, mainly focusing on the Dirham's depreciation and how the central bank responded. Unlike typical financial crises, COVID-19 was not sparked by financial instability but by a health emergency that disrupted global supply and demand. This shock was felt quickly and intensely, shaking up international trade, production, and consumption, directly impacting Morocco's economy.

For our simulation, we are basing everything on the actions the central bank took during the crisis to test the results of these measures. The pandemic caused a steep decline in demand, leading to significant disruptions in domestic and international markets. In Morocco, the Dirham dropped by around 4% against the US dollar in the first quarter of 2020. This was mainly driven by rising uncertainty, with markets reacting to the possibility of even more economic turbulence. The collapse in demand, combined with issues like supply chain disruptions and a widening trade deficit, placed an immense pressure on the currency.

To deal with this, Morocco's central bank cut the policy interest rate by 0.5% in Q2 2018 and Q1 2019. These moves boosted the domestic economy and injected liquidity into the market. Despite the depreciation, the Dirham did not fall as drastically as expected, mainly due to Morocco's managed exchange rate system. This system allowed the central bank to adjust exchange rate bands, offering the flexibility to cope with the mounting economic pressure.

We found in our simulation that, even with the depreciation, the Dirham held steady in terms of its fundamental value. This suggests that the central bank's monetary policy framework successfully

controlled inflation and stabilised the currency. Strategic interventions, including tapping into foreign reserves, helped limit the Dirham's decline. This kind of flexibility in managing the currency stands in contrast to countries with fixed exchange rate systems, which have less room to manoeuvre during crises. Take Argentina during the 2001 crisis; for example, the government could not adjust its currency peg, which only deepened the economic collapse (Calvo, 2006).

Similarly, countries in monetary unions, like Greece during the 2008 financial crisis, struggled to adjust their currency. As part of the Eurozone, Greece could not devalue its currency or change its monetary policy, making it much harder to regain economic stability (Buiter and Grafe, 2002). However, Morocco's managed exchange rate system allowed for greater flexibility to handle the financial fallout from the pandemic, offering an advantage over countries with more rigid monetary systems.

By simulating the effects of the central bank's actions, we can see how vital exchange rate flexibility and adaptable monetary policies are when stabilising an economy during a global crisis. Morocco's response to COVID-19 underscores the value of a managed exchange rate system, showing that flexibility can help countries navigate external pressures with more resilience. This ability to adapt is something that fixed exchange rate systems struggle with, as their lack of flexibility can worsen the impact of crises and slow recovery.

CONCLUSION

This paper introduces an SVAR model to explore key macroeconomic variables and their relationship with exchange rate dynamics, focusing on Morocco's economy under various crisis scenarios. The findings offer valuable insights into the behaviour of these variables in response to economic shocks, with key results that align and contrast with existing literature.

One of the key results from our simulation is the response of the policy rate, foreign reserves, and trade balance during different types of crises. In the case of an exchange rate crisis, we found a pronounced reduction in the policy rate, an improvement in the trade balance, and an increase in foreign exchange reserves. This contrasts with the findings of Calvo and Mendoza (2000), who observed a depletion of foreign reserves during financial crises, especially in countries with rigid exchange rate systems. Our results suggest that Morocco's managed exchange rate system, with more flexibility, helps mitigate this typical outcome by allowing for foreign exchange interventions that stabilise the currency and reserves.

Similarly, when examining a trade balance crisis, our simulation shows a delayed increase in the policy rate and an appreciation of the domestic currency. This is consistent with the Eurozone crisis (Feldstein, 2012), where currency depreciation was a key issue. However, it also highlights Morocco's advantage in adjusting its exchange rate bands, unlike Greece and other Eurozone countries that could not devalue their currency during the crisis. The ability of Morocco to address the trade imbalance with flexible policy tools contrasts with the rigidity of monetary unions, which face significant challenges in responding to such shocks.

The simulation of a foreign exchange reserves crisis reveals a sharp depreciation of the Dirham against the dollar, followed by a J-shaped response in the policy rate. This result is comparable to findings in the 2001 Argentine crisis (Alesina and Barro, 2002), where rigid exchange rate mechanisms prevented timely adjustments, leading to sharp currency devaluation. The flexibility inherent in Morocco's managed system allows for better management of foreign exchange reserves and currency depreciation, highlighting the advantage of such systems in navigating external shocks compared to currency-board arrangements.

In the context of the COVID-19 crisis, the simulation reveals liquidity challenges marked by a significant depreciation of the Dirham and a decline in foreign exchange reserves. This aligns with existing literature on crises triggered by external shocks, where heightened market uncertainty leads to currency depreciation and reserves depletion. However, the study provides new insights into how Morocco's exchange rate management and monetary policy responses can cushion the effects of such

a crisis, especially when compared to countries like Argentina in the 1990s, where rigid policies contributed to economic instability (Calvo and Mendoza, 2000).

The findings are also relevant to countries in monetary unions, as they face difficulties managing exchange rate crises without the ability to adjust their currency. Our results support the arguments made by Buitter and Grafe (2002), who emphasised the challenges faced by Eurozone countries during the 2008 financial crisis due to their inability to devalue the euro. In contrast, Morocco's ability to adjust exchange rate bands and policy rates offers it greater flexibility, as countries within a currency union lack this independence.

By comparing our simulation results with these existing studies, we confirm that flexibility in exchange rate policy, whether through managed systems or broader fiscal tools, is crucial for economic stability during crises. This model's insights suggest that countries with more adaptable systems, like Morocco, have a significant advantage in responding to external economic shocks, as opposed to countries with fixed exchange rate regimes or those within monetary unions.

In summary, our findings reinforce and build upon existing literature by demonstrating how Morocco's managed exchange rate system offers resilience in the face of economic shocks. This research provides critical lessons for economies, including those in monetary unions and countries with currency board systems, on the importance of flexibility in managing crises and maintaining economic stability.

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APPENDIX

EXPLANATION OF CONSTRAINTS AND THE ECONOMIC BACKGROUND FOR THEIR USAGE

C1: Misalignment refers to the percentage difference between the nominal and real effective exchange rates, calculated using the bilateral exchange rates between Morocco and its trading partners. This constraint captures the idea that exchange rate misalignments can significantly affect a country's export and import competitiveness. As Gros (1997) pointed out, misalignments can lead to trade imbalances and economic instability, particularly in emerging markets. A misaligned exchange rate can harm export competitiveness or inflate import costs, directly influencing Morocco's balance of payments and external sector performance.

C2: The exchange rate is crucial in shaping imports and exports. A sharp depreciation of the local currency boosts exports by making them cheaper abroad, while imports become more expensive, reducing foreign demand. This aligns with Krugman (1999), who discussed how exchange rate fluctuations heavily influence trade balances, especially in economies like Morocco that rely on external trade. Conversely, an increase in imports can exert downward pressure on the local currency, creating a feedback loop that further impacts the exchange rate.

C4: In a fixed exchange rate system, the central bank uses foreign reserves to meet domestic market demand and stabilise the exchange rate. A sudden shock to the trade balance, such as worsening terms of trade or increased imports, depletes these reserves as the central bank intervenes to maintain the peg. This dynamic was evident in Morocco during Q2 2017, when external imbalances strained foreign reserves. According to Mishkin (1991), central bank interventions using reserves are crucial for maintaining exchange rate stability, particularly in economies with fixed or managed exchange rate systems.

C5: Cash currency is vital in Morocco's domestic trade, where many transactions are still conducted in cash. A shock to the trade balance influences fiduciary money by affecting the supply of Dirhams in the economy. When foreign reserves decline due to trade imbalances, the central bank may adjust the money supply to meet domestic demand, further influencing inflation and currency movements. Gros (1997) emphasised that changes in the money supply, especially in cash-based economies, directly impact inflation and exchange rate stability.

C6: In economies with reliable data, past behaviour influences the evolution of various economic variables. Historical trends and autocorrelation in macroeconomic variables are essential for forecasting future developments. This idea is backed by econometric models, like vector autoregressions (VAR), which often rely on historical data to predict the behaviour of economic indicators (Li et al., 2021). For Morocco, past exchange rate trends, trade balance, and foreign reserves are valuable for predicting future shocks and economic reactions.

C7: Foreign exchange reserves are the primary tool for the central bank to intervene in the currency market. A reserve shock, whether from declining foreign inflows or other external factors, reduces the central bank's ability to stabilise the currency. This immediately impacts the exchange rate, as reserves are used to defend the fixed rate. As Reinhart and Rogoff (2009) noted, the depletion of reserves during external shocks can undermine investor confidence, leading to speculative attacks and further pressure on the exchange rate.

C8: The policy rate is critical for central banks to manage monetary policy and control inflation. Unlike foreign reserves, changes in the policy rate typically respond to exchange rate shocks, such as significant currency depreciation or appreciation. Mishkin (1991) suggested that central banks adjust interest rates in response to inflationary pressures or currency fluctuations, influencing exchange rate expectations and investor behaviour in future periods.

C10: Misalignment directly affects the competitiveness of a country's goods and services globally. Thus, changes in misalignment from previous periods strongly influence the trade balance, particularly on the export side. This is especially relevant for Morocco, where exchange rate movements significantly impact export competitiveness in sectors like textiles and agriculture. Krugman (1999) emphasised that exchange rate misalignments often lead to shifts in trade balances, requiring policy adjustments to restore equilibrium.

C13: The trade balance is closely linked to foreign exchange reserves in a fixed exchange rate system. When reserves are depleted due to a trade shock, the central bank faces challenges in maintaining the exchange rate, often leading to domestic currency depreciation. This phenomenon is particularly relevant for Morocco, where key imports like oil and wheat heavily influence the trade balance. Gros (1997) argued that rapid depreciation due to a reserves shock increases the cost of imports, worsening the trade balance and intensifying inflationary pressures.

C15: The policy rate regulates domestic demand, especially in response to external shocks like changes in the trade balance. A shock to the trade balance triggers the central bank to adjust the policy rate in subsequent periods to mitigate inflationary pressures, as discussed by Mishkin (1991). In Morocco, the central bank uses the policy rate to control inflation and manage the exchange rate, especially during external economic instability.

C17: Changes in the policy rate have a twofold impact on misalignment in subsequent periods. Adjustments to the policy rate affect both the exchange rate and the consumer price index, essential components in calculating misalignment. Literature on monetary policy transmission mechanisms (Mishkin, 1991) supports this, showing that interest rate changes influence inflation and exchange rates, affecting the currency's actual value.

C19: A change in the policy rate also significantly influences currency circulation in the periods following the adjustment. In Morocco, where cash remains dominant in domestic trade, shifts in the policy

rate influence the amount of fiduciary money in circulation, impacting inflation and overall economic activity. Gros (1997) noted that changes in interest rates affect cash demand and the broader money supply, influencing inflation and exchange rate stability in cash-based economies like Morocco

Figure A1 SVAR model variables

Note: See the online version of *Statistika: Statistics and Economy Journal* No. 4/2025: <<https://doi.org/10.54694/stat.2024.57>>.
Source: Computed by authors, EViews

Figure A2 Impulse responses to generalised standard deviation shocks in the SVAR model

Note: See the online version of *Statistika: Statistics and Economy Journal* No. 4/2025: <<https://doi.org/10.54694/stat.2024.57>>.
Source: Computed by authors, EViews

Figure A3 Variance decomposition of the SVAR model via Cholesky factorisation

Note: See the online version of *Statistika: Statistics and Economy Journal* No. 4/2025: <<https://doi.org/10.54694/stat.2024.57>>.
Source: Computed by authors, EViews

Figure A4 Historical variance decomposition of the SVAR model using Cholesky weights

Note: See the online version of *Statistika: Statistics and Economy Journal* No. 4/2025: <<https://doi.org/10.54694/stat.2024.57>>.
Source: Computed by authors, EViews

Figure A5 Response of SVAR model variables to an exchange rate crisis

Note: See the online version of *Statistika: Statistics and Economy Journal* No. 4/2025: <<https://doi.org/10.54694/stat.2024.57>>.
Source: Computed by authors, EViews

Figure A6 Response of SVAR variables to a trade balance crisis

Note: See the online version of *Statistika: Statistics and Economy Journal* No. 4/2025: <<https://doi.org/10.54694/stat.2024.57>>.
Source: Computed by authors, EViews

Figure A7 Response of the SVAR variables to a foreign exchange reserve crisis

Note: See the online version of *Statistika: Statistics and Economy Journal* No. 4/2025: <<https://doi.org/10.54694/stat.2024.57>>.
Source: Computed by authors, EViews

Figure A8 Response of the SVAR model variables to the COVID-19 economic crisis

Note: See the online version of *Statistika: Statistics and Economy Journal* No. 4/2025: <<https://doi.org/10.54694/stat.2024.57>>.
Source: Computed by authors, EViews

Performance Evaluation of K-Means Clustering Algorithm Using Some Robust Distances: a Case Study on Seismic Data in Sumatra

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Abstract

Clustering is an unsupervised learning technique that categorizes data into groups based on inherent patterns and similarities, with K-means being one of the most common methods. K-means clustering is particularly susceptible to outliers because of its dependence on non-robust distances (such as the most used Euclidean distance). To address this issue, robust distance metrics such as a new Standardized Euclidean Robust distance and Mahalanobis Robust distance have been discussed in this paper, which will reduce the influence of outliers and, at the same time, improve clustering accuracy empirically. The main objective of this study is to investigate the impact of applying robust distance metrics in the K-means clustering and to identify the most suitable distance metric for seismic data containing outliers. The findings indicate that robust distance measures outperform the non-robust distances in accuracy, yielding superior outcomes for minimum-valued indices such as Davies-Bouldin, Xie-Beni, and Ball-Hall indices, as well as maximum-valued indices such as Calinski-Harabasz and Dunn indices.

Keywords

Clustering, k-means, outliers, robust distance

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INTRODUCTION

Clustering is an important technique in machine learning and data mining, allowing the partitioning of large datasets into meaningful groups based on intrinsic similarities. Among the many clustering algorithms available, K-means is essential in data mining and is the most straightforward and commonly utilized method (Mussabayev et al., 2023).

K-means clustering algorithm can be used with various distances metric, where the most popular one is using Euclidean distance, see e.g. Patel and Mehta (2012), Kapil and Chawla (2016). Other popular distance including Mahalanobis distance, such as in Nelson (2012) which integrated the Mahalanobis distance into the traditional K-means clustering algorithm. The experiment's results show the advantages of using the Mahalanobis distance in clustering. Brown (2022) discuss improvements to the traditional K-means clustering algorithm by incorporating Mahalanobis distance. They provide experimental results that demonstrate the effectiveness of this method compared to standard Euclidean distance k-means. Ghazal et al. (2021) explores the effects of various distance metrics on the performance of the K-means clustering algorithm. Each metric is evaluated for its performance in various datasets, providing insight into how different distance measurements handle high-dimensional or complex data. The study shows that distance metrics (Euclidean, Manhattan, Mahalanobis, and Chebyshev distances) have a significant influence on the performance of K-means clustering, with the Mahalanobis-Euclidean distance yielding the best accuracy compared to other metrics.

The K-means clustering algorithm is prone to several challenges in practical applications. This algorithm is particularly sensitive to outliers (e.g. Zhang et al., 2021). Outliers can be broadly defined as data instances that significantly diverge from established norms within a data set or from anticipated behavioral concepts (Smiti, 2020). More generally, outliers are data points that exhibit a significant deviation from most of the dataset and can distort clustering results. A robust clustering method is required to mitigate the impact of outlier data (Huber and Ronchetti, 2011).

In this study, we extend the result from Ghazal et al. (2021) by studying K-means clustering using several new robust distance metrics, namely Standardized Euclidean Robust and Mahalanobis Robust distance. This research aims to investigate the impact of these robust distance metrics on clustering accuracy and evaluate their effectiveness in handling seismic data outliers from Sumatra Island. Specifically, this study addresses the following research objectives:

1. To assess whether robust distance metrics improve clustering accuracy in K-means clustering when applied to seismic data containing outliers.
2. To identify the most effective distance metric for clustering seismic data by comparing clustering outcomes based on multiple internal evaluation indices.

To achieve these objectives, we formulate the following hypotheses:

1. K-means clustering with robust distance metrics (Standardized Euclidean Robust or Mahalanobis Robust) will yield higher clustering accuracy than traditional Euclidean distance.
2. The clustering results using robust distance metrics will produce more compact and well-separated clusters, as indicated by superior values in internal evaluation indices such as Davies-Bouldin, Xie-Beni, Calinski-Harabasz, Dunn, and Ball-Hall indices.

The rest of the paper is structured as follows. Section 1 introduces the background of the problem. Section 2 discusses the methods used in the study. Finally, Sections 3 and 4 present the results and discussion, followed by the conclusion at the end of the paper.

1 LITERATURE SURVEY

Clustering is an important technique in data mining and machine learning, especially for grouping data that does not have explicit labels. The K-means algorithm has become one of the most commonly used methods for clustering due to its ease of implementation and computational efficiency (Lantz, 2019).

Several related and important results can be summarized as follows. Maulik and Bandyopadhyay (2002) comprehensively evaluate several clustering algorithms and the effectiveness of different clustering validity indices. This paper compares the performance of K-Means, agglomerative hierarchical clustering (single linkage), and a simulated annealing-based clustering technique in terms of their ability to partition data accurately. The study uses Euclidean distance for K-means and simulated annealing algorithms to compute the squared distance between points and cluster centroids. Additionally, the paper explores the role of various validity indices, including the Davies-Bouldin index, Dunn's index, Calinski-Harabasz index, and a newly developed index I, which measures the quality of clustering results across diverse datasets.

Many studies have used distance metrics like Euclidean and Manhattan. Patel and Mehta (2012) enhanced the K-means algorithm by evaluating Euclidean, Manhattan, and Minkowski distances. Euclidean distance proved more effective for clusters of similar size, whereas Manhattan distance was better for noisy, high-dimensional data. Minkowski provided adaptability but required precise parameter adjustment. Kapil and Chawla (2016) examined Euclidean and Manhattan distances, demonstrating that Euclidean distance was more efficient, requiring fewer repetitions, resulting in lower the within-cluster sum of squared errors (WSS), and exhibiting a faster runtime, proving more effective for their datasets.

Raeisi and Sesay (2022) proposed a new distance metric to improve K-means clustering, particularly for different cluster sizes. Based on Canberra distance, this metric generates larger clusters for centroids that are farther distant from the origin and smaller clusters for those that are nearer. Compared to conventional metrics such as Euclidean and Manhattan, simulations indicate that it generates more precise clusters, which is especially beneficial in domains like autonomous cars. The research determines that the novel metric improves K-means efficacy in irregular data distributions.

Brown (2022) presented a non-trivial integration of K-means clustering and Mahalanobis distance. The method enhances the K-means clustering process by replacing the standard Euclidean distance metric with the Mahalanobis distance. This modification allows the algorithm to account for the covariance among variables in the dataset. The evaluation results indicate that the Mahalanobis distance-based K-means clustering algorithm exhibits superior accuracy compared to comparable studies.

K-means has a major weakness: its sensitivity to outliers because it uses the average to determine the centroid and its dependence on non robust distances (such as the mostly used Euclidean distance). This weakness is making it vulnerable to distortions caused by outliers or noise in the data. Outliers can significantly affect clustering results and reduce accuracy (Zhao, Ying and Karypis, 2002).

Various approaches have been developed to address this issue. Hawkins (1994) introduces the Feasible Solution Algorithm (FSA) for computing the Minimum Covariance Determinant (MCD) estimator, which is crucial for robust multivariate data analysis. Hardin and Rocke (2004) extend the MCD estimator to the multiple cluster setting for robust outlier detection. This paper develops a method that effectively identifies outliers across multiple clusters using Mahalanobis-type distances based on robust estimates of location and scatter derived from the MCD. Hubert and Debruyne (2010) highlight the MCD estimator's efficacy in identifying multivariate outliers. They examine its extensions and applications in topics such as robust principal component analysis and regression. The MCD's effectiveness in various fields, such as finance and image analysis, makes it an essential tool in robust statistical methods. Hubert et al. (2018) comprehensively review the MCD estimator, a highly robust method for estimating multivariate location and scatter while effectively managing outliers. The paper discusses the fast algorithm available for computing the MCD, along with its various applications and extensions in fields such as classification, clustering, and other areas of applied and methodological multivariate statistics, demonstrating its versatility in computational statistics.

2 METHODS

2.1 Distance measure

The distance measure must be determined before clustering. The distance measure reflects the degree of separation between data points and should align with the characteristics used to differentiate clusters within the dataset (Cao et al., 2012; Huang, 2008)

2.1.1 Euclidean distance

Euclidean distance is the primary measure used in cluster analysis to quantify the distance between data objects and the centroids of their respective clusters (Johnson and Wichern, 2002). Euclidean distance, D_e , between two data points x_i and x_j is described as:

$$D_e(x_i, x_j) = \left(\sum_{k=1}^d |x_{ik} - x_{jk}|^2 \right)^{\frac{1}{2}}, \quad (1)$$

where x_{ik} and x_{jk} each represent the k -th dimension of x_i and x_j and d is the number of dimensions (Xu and Wunsch, 2005).

2.1.2 Minkowski distance

The Minkowski distance is a generalization of several well-known distance metrics, such as Euclidean and Manhattan distances. It is a parameterized distance metric in a normed vector space determined by a parameter p . Depending on the p -value, the Minkowski distance can represent different distance measures. The Minkowski distance between two data points x_i and x_j in d -dimensional space is given by:

$$D_{Mink}(x_i, x_j) = \left(\sum_{k=1}^d |x_{ik} - x_{jk}|^p \right)^{\frac{1}{p}}, \quad (2)$$

where x_i and x_j are the two data points, d is the number of dimensions, p is the parameter that controls the type of distance metric: when $p = 1$, this becomes the Manhattan distance, when $p = 2$, it becomes the Euclidean distance and when $p \rightarrow \infty$, it becomes the Chebyshev distance.

2.1.3 Manhattan distance

The Manhattan distance between two data points is defined as the sum of the absolute differences of their coordinates. This distance is also known as a city block, square, taxi, or L_1 distance. Mathematically, the distance between x_i and x_j is defined as:

$$D_{Mn}(x_i, x_j) = \sum_{k=1}^d |x_{ik} - x_{jk}|. \quad (3)$$

2.1.4 Mahalanobis distance

The Mahalanobis distance is the alternative distance applied considering the correlation effect between variables. The Mahalanobis distance is defined as the distance between two points that involves the covariance or correlation between variables. The Mahalanobis distance between two objects is expressed in the form of vectors and matrices:

$$D_{Mh}(x_i, x_j) = (x_i - x_j)^T S^{-1} (x_i - x_j), \quad (4)$$

with S being the sample covariance matrix.

2.1.5 Canberra distance

Canberra distance measure quantifies the amount of absolute fractional difference between the variables of a pair of data points. This measurement is defined as follows:

$$D_{Can}(x_i, x_j) = \sum_{k=1}^d \frac{|x_{ik} - x_{jk}|}{|x_{ik}| + |x_{jk}|}, \quad (5)$$

where x_{ik} and x_{jk} are components of vectors x_i and x_j , and d is the dimension of the vector. This measurement is sensitive to small changes when both coordinates approach zero.

2.1.6 Chebyshev distance

The Chebyshev distance between two points and in a multi-dimensional space is mathematically defined as:

$$D_{Cb}(x_i, x_j) = \max_{1 \leq k \leq d} (|x_{ik} - x_{jk}|), \quad (6)$$

where: x_i and x_j are two points in a d -dimensional space, x_{ik} and x_{jk} are the k -th feature (coordinate) of the points x_i and x_j , respectively and the maximum is taken over all dimensions k from 1 to d .

2.1.7 Standardized Euclidean distance

The standardized Euclidean distance is defined as the Euclidean distance between data points divided by their standard deviation. The standardized Euclidean distance between x_i and x_j is mathematically represented as:

$$D_{se}(x_i, x_j) = \left(\sum_{k=1}^d \left| \frac{x_{ik} - x_{jk}}{s_k} \right|^2 \right)^{\frac{1}{2}}, \quad (7)$$

with s_k being the standard deviation of dimension k (Xu and Tian, 2015).

2.2 Robust distance measure

Outliers can substantially affect distance measures and other statistical computations in data analysis, particularly multivariate data. Robust methods such as the Minimum Covariance Determinant (MCD) minimize the effect of outliers and improve distance calculation. This section discusses the Minimum Covariance Determinant (MCD) method, both with the Standard Euclidean Robust Distance and the Mahalanobis Robust Distance based on MCD.

2.2.1 Minimum Covariance Determinant (MCD)

The Minimum Covariance Determinant (MCD) method is a robust statistical technique used to estimate the covariance matrix and mean of multivariate data (Hubert and Debruyne, 2010). In 1984, Peter Rousseeuw introduced it as a robust alternative to traditional covariance estimation techniques subject to outliers. Within the framework of robust distance, the MCD technique provides a robust covariance estimate, subsequently employed to compute the distance between two data points.

This method aims to find a subset of size h from the entire set of observations, where the covariance matrix of the subset has the smallest determinant among all possible combinations. The subset S_h is assumed to contain data that does not include outliers.

$$\hat{\mu}_{MCD} = \frac{1}{h} \sum_{i=1}^h x_i, \tag{8}$$

This is the estimated mean for the subset S_h with the smallest determinant using the MCD.

$$\hat{\Sigma}_{MCD} = \frac{1}{h-1} \sum_{i=1}^h (x_i - \hat{\mu}_{MCD})(x_i - \hat{\mu}_{MCD})^T. \tag{9}$$

This is the covariance estimate for the subset S_h with the smallest determinant, calculated using the MCD.

2.2.2 Standardized Euclidean Distance Robust (using MCD)

The robust standardized Euclidean distance between x_i and x_j in a dataset with d dimensions is given by:

$$D_{robust_se}(x_i, x_j) = \left(\sum_{k=1}^d \left(\frac{|x_{ik} - x_{jk}|}{\sqrt{\hat{\sigma}_{k,rob}^2}} \right)^2 \right)^{\frac{1}{2}}, \tag{10}$$

where: x_i and x_j are the two data points, each with d features, x_{ik} and x_{jk} are the values of the k -th feature (dimension) for data points x_i and x_j , respectively and $\hat{\sigma}_{k,rob}^2$ is the robust estimate of the variance for the k -th feature, computed using the Minimum Covariance Determinant (MCD) method.

2.2.3 Mahalanobis Robust Distance (using MCD)

The robust Mahalanobis distance between two points x_i and x_j is given by:

$$D_{M,rob}(x_i, x_j) = (x_i - x_j)^T \Sigma_{rob}^{-1} (x_i - x_j), \tag{11}$$

where: x_i and x_j are points in d -dimensional space and Σ_{rob} is the robust covariance matrix estimated from the data.

2.3 Cluster validity

The process of assessing the outcomes of clustering algorithms is referred to as cluster validity (Halkidi, 2001). Internal criteria are crucial in clustering as they evaluate clustering quality independent of external information or labels.

2.3.1 The Ball-Hall index

The Ball-Hall index measures points' mean dispersion (variance) within clusters. It is defined as the mean of the sum of squared distances between each point and the centroid of its cluster:

$$BH_{index} = \frac{1}{K} \sum_{k=1}^K \frac{1}{n_k} \sum_{i \in C_k} x_i - c_k^2, \tag{12}$$

where: K is the number of clusters, n_k represents the number of points within the k -th cluster, C_k is the set of points belonging to the k -th cluster, x_i represents the i -th data point within the k -th cluster, c_k is the centroid of the k -th cluster and $\|x_i - c_k\|^2$ is the squared Euclidean distance between the point x_i and the centroid c_k .

2.3.2 The Calinski-Harabasz index

The Calinski-Harabasz index $S(k)$ for a given number of clusters k is calculated as:

$$S(k) = \frac{B(k)/(k-1)}{W(k)/(n-k)}, \quad (13)$$

where: $W(k)$ is the within-cluster sum of squares (unexplained variance) and defined as follows:

$$W(k) = \sum_{i=1}^k \sum_{x \in C_i} x - c_i^2, \quad (14)$$

where: k is the number of clusters, C_i is the i -th cluster, x represents data point in cluster C_i , c_i is the centroid of cluster C_i and $\|x - c_i\|^2$ is the squared Euclidean distance between a point x and the centroid c_i . $B(k)$ is the between-cluster sum of squares (explained variance) and formed as:

$$B(k) = \sum_{i=1}^k n_i \|c_i - c\|^2, \quad (15)$$

where: n_i is the number of data point in cluster C_i , c_i is the centroid of cluster C_i , c is the global centroid (centroid of all data points) and $\|c_i - c\|^2$ is the squared Euclidean distance between the centroid of cluster C_i and the global centroid c .

2.3.3 The Davies-Bouldin index

The Davies-Bouldin (DB) index is a metric used to assess the performance of clustering algorithms. This method measures clustering quality based on inherent data characteristics and factors (Davies and Bouldin, 1979), and the calculation is performed using the following formula:

$$DB = \frac{1}{K} \sum_{k=1}^K \max_{i \neq j} \left(\frac{\delta_i + \delta_j}{d_{ij}} \right). \quad (16)$$

The variable $d_{ij} = \|c_i - c_j\|^2$, represents the distance between the centroids of clusters C_i and C_j , δ_i refers to the standard deviation of the distance of objects in C_i to the centroid of the cluster and δ_j refers to the standard deviation of the distance of objects in C_j to the centroid of the cluster. A lower DB index value signifies a better clustering solution.

2.3.4 The Det-Ratio index

Let W denote the pooled within-cluster covariance matrix, computed as a weighted sum of individual cluster covariance matrices, and let T represent the total covariance matrix of the entire dataset. The Det-Ratio index calculates the ratio of the determinants of W and T . The index compares the entire dataset's overall dispersion (spread) with the spread within individual clusters (Milligan and Cooper, 1985). The Det-Ratio index is computed as:

$$Det - Ratio = \frac{\det(W)}{\det(T)}, \quad (17)$$

where: $det(W)$ is the determinant of the pooled within-cluster covariance matrix and $det(T)$ is the determinant of the total covariance matrix of the dataset. Formula for $det(W)$:

$$det(W) = \sum_{i=1}^k (n_i - 1) \Sigma_i, \tag{18}$$

where: k is the number of clusters, n_i represents the number of points in i -th cluster, Σ_i is the covariance matrix of i -th cluster, W is the pooled within-cluster covariance matrix, and $det(W)$ is the determinant of this pooled matrix. Formula for $det(T)$:

$$det(T) = (n - 1) \Sigma, \tag{19}$$

where: n is the total number of data points in the dataset, Σ is the covariance matrix of the entire dataset, T is the total covariance matrix, and $det(T)$ is the determinant of this total matrix.

2.3.5 The Dunn index

The Dunn index quantifies the ratio of the smallest distance between clusters to the most significant distance within clusters (Dunn, 1973) and the index is denoted by:

$$Dunn = \frac{\min_{1 \leq i < j \leq K} d(C_i, C_j)}{\max_{1 \leq k \leq K} diam(C_k)}, \tag{20}$$

where:

- K is the number of clusters.
- $d(C_i, C_j)$ is the distance between clusters C_i and C_j , defined as the minimum distance between any point in C_i and any point in C_j : $d(C_i, C_j) = \min_{x \in C_i, y \in C_j} \|x - y\|$.
This is the minimum inter-cluster distance.
- $diam(C_k)$ is the diameter of cluster C_k defined as the maximum distance between any two points within the same cluster: $diam(C_k) = \max_{x, y \in C_k} \|x - y\|$.
This is the maximum intra-cluster distance, representing the spread or dispersion within the cluster.

The clustering is better when the Dunn index value is higher.

2.3.6 The Silhouette index

The Silhouette index evaluates how well each data point x_i fits into its assigned cluster by comparing its cohesion within the cluster and its separation from the nearest neighboring cluster. The index is computed as:

$$S = \frac{1}{n} \sum_{i=1}^n \frac{(b(x_i) - a(x_i))}{\max\{a(x_i), b(x_i)\}}, \tag{21}$$

where:

- n is the total number of data points.
- Cohesion: $a(x_i)$ is the average distance between x_i and all other points in the same cluster C_i :

$$a(x_i) = \frac{1}{|C_i| - 1} \sum_{x_j \in C_i, j \neq i} d(x_i, x_j). \tag{22}$$

Separation: $b(x_i)$ is the minimum average distance between x_i and all points in the nearest cluster C_k :

$$b(x_i) = \min_{C_k \neq C_l} \left(\frac{1}{|C_k|} \sum_{x_j \in C_k} d(x_i, x_j) \right), \tag{23}$$

$\max\{a(x_i), b(x_i)\}$ ensures that the larger of the two values $a(x_i)$ or $b(x_i)$ is used to normalize the result.

Silhouette index ranges from -1 to 1, the maximum index value calculates the best possible clusters within the data.

2.3.7 Xie-Beni index (XB)

The Xie-Beni index is an index of fuzzy clustering, but it is also applicable to crisp clustering. It is defined as the quotient between the mean quadratic error and the minimum of the minimal squared distances between the points in the clusters (Xie and Beni, 1991). For crisp clustering, this is equivalent to the within-cluster sum of squares (WGSS) divided by the total number of points N . It represents the average squared distance between the data points and the centroid (barycenter) of their assigned cluster.

The inter-cluster distance $\delta_1(C_k, C_l)$ is calculated as the minimum distance between the points of two clusters C_k and C_l , based on their centroids. The formula is:

$$XB_{index} = \frac{1}{N} \frac{WGSS}{\min_{k < l} \delta_1(C_k, C_l)^2}, \tag{24}$$

where:

- N is the total number of data points.
- $WGSS$ is the within-cluster sum of squares, which is the sum of the squared distances between points in each cluster and their corresponding cluster centroids.

$$WGSS = \sum_{i=1}^K \sum_{x \in c_k} \|x - c_k\|^2, \tag{25}$$

where:

- c_k is the k -th cluster, x is a point in cluster c_k , and $\|x - c_k\|^2$ is the squared Euclidean distance between point x and the centroid c_k
- $\delta_1(C_k, C_l)$ is the minimum inter-cluster distance, which is the minimum distance between the centroids of clusters c_k and c_l .

$$\delta_1(c_k, c_l) = \|c_k - c_l\|, \tag{26}$$

where: c_k and c_l are the centroids of clusters C_k and C_l , respectively.

2.4 Spatial outlier detection

A mean-based approach can be used to detect outliers in multivariate data with spatial variables (Lu et al., 2004). This technique discovers spatial outliers by recognizing items that significantly deviate from their neighboring spatial locations (Shukla et al., 2021).

Steps for Spatial Outlier Detection Based on the Mean Algorithm.

- Input Data and Setup: define the spatial data $X = \{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\}$, a fixed number k of nearby neighbors, a function f , and a threshold $\theta = \chi_{s;1-\alpha}^2$ that has already been set, where s represents the degrees of freedom (df) in the chi-square distribution.
- Standardization: standardize each variable values of each spatial point.
- Nearest neighbors: identify the k -nearest neighbors set $N, N_k(\mathbf{x}_i)$ for each spatial point \mathbf{x}_i .
- Neighborhood function: calculate neighborhood function g for each spatial point \mathbf{x}_i such that $g_j(\mathbf{x}_i) = \text{mean of the data } \{f_j(\mathbf{x}) : \mathbf{x} \in NN_k(\mathbf{x}_i)\}$ and the function used for comparing $h(\mathbf{x}_i) = f(\mathbf{x}_i) - g(\mathbf{x}_i)$.
- Outlier determination: compute the squared difference $d^2(\mathbf{x}_i)$, $d^2(\mathbf{x}_i) = (h(\mathbf{x}_i) - \mu_s)^T \sum_s^{-1} (h(\mathbf{x}_i) - \mu_s)$, and compare it to the threshold θ . If $d^2(\mathbf{x}_i) \geq \theta$ is considered a spatial outlier.

2.5 Modified K-means algorithm

1. Initialization:

- Centroid initialization: choose an initial set of centroids.
- Prepare for Distance Metric Selection: Euclidean, Standardized Euclidean, Maximum, Manhattan, Canberra, Minkowski, Mahalanobis and standardized Euclidean Robust and Mahalanobis Robust (using Minimum Covariance Determinant).

2. Distance calculation (modification from procedure 2):

- Euclidean Distance: for standard k-means.
- Manhattan, Canberra, etc., can be implemented depending on the structure of your data.
- Mahalanobis Distance: involves calculating the covariance matrix, or for robust k-means, the MCD estimator.
- Robust Distance Metrics like MCD, ensure that the robust covariance matrix (or other robust statistics) is used in the distance calculations.

3. Cluster assignment: based on the distance calculations, assign each point to the closest centroid.

4. Centroid update: recalculate the centroids based on the current cluster assignments.

5. Convergence check:

Repeat steps 2 to 4 until the centroids stabilize (no change between iterations) or the algorithm reaches the predefined number of iterations.

Modified Step 6: Determining Optimal k , the number of clusters, (from Procedure 3):

- Loop over k values: run the clustering algorithm for various values of k .
- For each value of k , calculate the following internal indices:
 - Davies-Bouldin Index: lower values are better.
 - Silhouette Score: higher values indicate better clustering.
 - Calinski-Harabaz, Dunn, Xie-Beni, Ball-Hall, Determinant-Ratio.
- After computing these indices for different values of k , select the value of k that provides the most favorable results across the indices.

3 RESULTS

In this study, we applied K-means clustering to Sumatra earthquake data using various distance metrics.

3.1 Data description

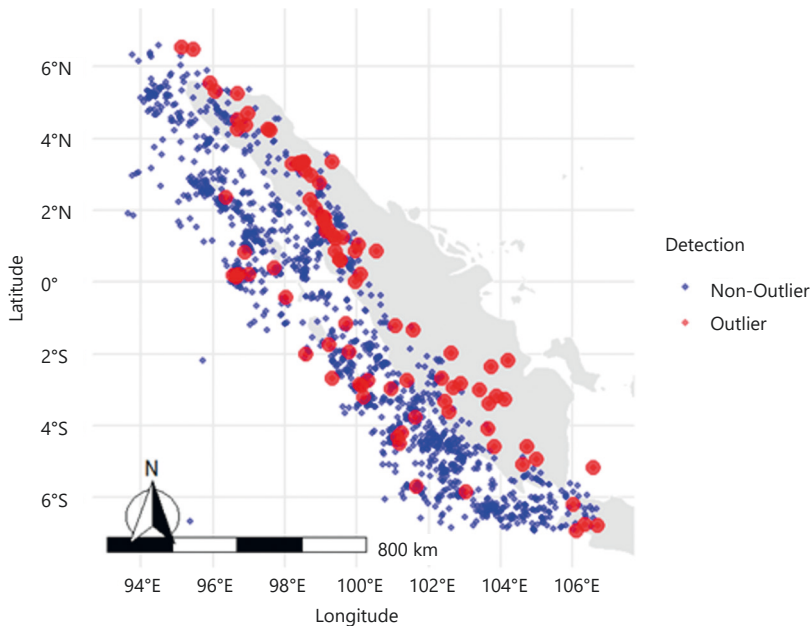
We collected earthquake data for Sumatra from January 1, 2017 to December 31, 2021.⁵ We apply the preprocessing by only includes 1 390 recorded earthquakes with a magnitude greater than 4.0 on the

⁵ From the website: <<http://earthquake.usgs.gov>>.

Richter scale and it contains variables such as latitude, longitude, depth, and magnitude. The K-means algorithm with several alternative robust distance measures implemented in R software version 4.3.2.

Before applying clustering, it is essential to detect whether spatial outliers exist in the data, as these outliers could significantly affect the accuracy of the clustering results. Outliers, especially in spatial data, represent unusual events or anomalies that deviate from general patterns and can provide essential insights. Therefore, using the mean algorithm (see Section 2.4), we detected outliers by considering the earthquake data's spatial (latitude, longitude) and non-spatial (depth, magnitude) dimensions. Ninety-one points, or 6.54% of the dataset, were identified as spatial outliers. Figure 1 illustrates the spatial location of outliers detected in the Sumatra earthquake data.

Figure 1 Spatial outliers detection in earthquake data



Source: Own research

3.2 Clustering accuracy

After detecting outliers, we applied the K-means clustering algorithm to the dataset using several distance metrics. The distance metrics evaluated include Euclidean, standardized Euclidean, robust standardized Euclidean, maximum, Manhattan, Canberra, Minkowski, Mahalanobis, and robust Mahalanobis.

Before performing clustering with the K-means algorithm, it is essential to determine the optimal number of clusters (k). The determination of the optimal k is carried out by comparing various internal indices, such as the Ball-Hall Index, Calinski-Harabasz Index (CH), Determinant Ratio (Det-Ratio), Davies-Bouldin Index (DB), Silhouette, Dunn, and Xie-Beni. The final k value is chosen based on the majority vote across these indices, selecting the k that is most frequently indicated as optimal by the majority of the indices for each distance metric.

Clustering accuracy was then evaluated by assessing the quality of the clusters generated by the algorithm. This was done by comparing the above internal indices, which provide different perspectives on the clustering structure. Table 1 presents the results of calculating these internal indices for each distance metric with k values varying from 2 to 6.

Table 1 Share of positive answers to job search questions and item-response probabilities

Distances	k	Ball-Hall	CH	DB	Det-Ratio	Dunn	Silhouette	Xie Beni
Euclidean	k = 2	1.273672	686.887	0.997194	2.71645	0.005846	0.400210	665.959
	k = 3	0.936657	1 289.818	0.732494	8.02887	0.005964	0.448821	548.981
	k = 4	0.748148	1 121.184	0.917919	12.50254	0.002291	0.368531	3 526.045
	k = 5	0.646471	1 036.303	0.908646	15.67819	0.001618	0.342675	6 291.175
	k = 6	0.621035	1 142.601	0.830398	25.76036	0.001520	0.360806	5 955.146
Standardized Euclidean	k = 2	1.273672	686.887	0.997194	2.71645	0.005846	0.400210	665.9598
	k = 3	0.936823	1 289.825	0.732525	8.03081	0.005964	0.448170	548.979
	k = 4	0.880946	1 013.581	0.870280	10.48739	0.003484	0.375172	1 483.779
	k = 5	0.639051	1 041.950	0.879309	16.00830	0.004813	0.329858	753.451
	k = 6	0.594372	1 037.654	0.921148	21.89493	0.000901	0.321425	1 489.52
Standardized Euclidean robust	k = 2	1.397652	797.894	0.760961	3.34890	0.003209	0.496180	2 048.134
	k = 3	0.975659	1 304.917	0.712285	8.32247	0.016157	0.457789	71.438
	k = 4	0.801777	1 076.272	0.964211	12.94352	0.002619	0.360394	2 352.817
	k = 5	0.682322	976.5731	0.975242	16.30381	0.001531	0.324290	6 003.763
	k = 6	0.630923	1 045.075	0.923768	23.43386	0.002007	0.336698	2 794.037
Maximum	k = 2	1.841707	519.720	1.382222	2.96414	0.001457	0.310419	6 341.465
	k = 3	0.944584	1 285.413	0.733669	8.01995	0.011600	0.443202	135.182
	k = 4	0.933743	1 031.092	0.811268	10.76380	0.007502	0.408614	348.757
	k = 5	0.634958	1 017.798	0.873809	15.39508	0.002024	0.335769	4 197.289
	k = 6	0.556546	951.830	0.877183	19.53233	0.001866	0.319942	4 541.747
Manhattan	k = 2	1.284324	684.613	1.003226	2.72209	0.006441	0.398207	549.133
	k = 3	0.956509	1 280.447	0.734501	7.98718	0.005851	0.446828	551.587
	k = 4	0.760856	1 106.612	0.911945	12.42045	0.001191	0.368243	11 167.37
	k = 5	0.698208	1 108.580	0.897459	17.28403	0.003368	0.345153	1 127.893
	k = 6	0.591964	1 022.215	0.921821	21.65069	0.002572	0.322703	2 272.086
Canberra	k = 2	1.673566	266.011	1.830434	1.40051	0.001084	0.163452	24 360.80
	k = 3	1.020687	807.530	0.906802	4.57418	0.000870	0.317712	22 330.27
	k = 4	0.930501	636.572	1.207194	5.48530	0.000400	0.251529	11 5581.2
	k = 5	0.849292	531.193	1.353911	6.22975	0.001291	0.212897	10 390.41
	k = 6	0.663275	513.754	1.157161	8.26076	0.000984	0.204716	15 881.63
Minkowski	k = 2	1.273672	686.887	0.997194	2.71645	0.005846	0.400210	665.959
	k = 3	0.936823	1 289.825	0.732525	8.03081	0.005964	0.448170	548.979
	k = 4	0.880946	1 013.581	0.870280	10.48739	0.003484	0.375172	1 483.779
	k = 5	0.639051	1 041.950	0.879309	16.00830	0.004813	0.329858	753.451
	k = 6	0.594372	1 037.654	0.921148	21.89493	0.000901	0.321425	18 489.52
Mahalanobis	k = 2	1.843878	520.086	1.380569	2.96581	0.001337	0.310156	7 526.662
	k = 3	0.950738	1 309.881	0.714538	8.30701	0.015120	0.462011	86.154
	k = 4	0.753744	1 103.287	0.943658	12.40621	0.002268	0.363824	3 566.359
	k = 5	0.645699	1 070.142	0.858568	17.07804	0.001902	0.335614	4 199.140
	k = 6	0.649216	1 115.020	0.832299	24.79341	0.002714	0.355516	1 733.396
Robust Mahalanobis	k = 2	1.407947	793.578	0.765406	3.35663	0.007641	0.494316	361.282
	k = 3	0.977242	1 301.184	0.714473	8.34197	0.016157	0.456395	71.572
	k = 4	0.87639	1 181.072	0.714400	12.33241	0.005851	0.441421	441.457
	k = 5	0.710398	914.041	1.088614	17.30273	0.001054	0.304277	13 278.71
	k = 6	0.710398	914.041	1.088614	17.30273	0.001054	0.304277	13 278.71

Source: Own research

3.3 Evaluation of internal indices

Based on the internal index evaluation results in Table 1, this can be clarified as follows:

1. For Euclidean distance, at $k = 2$, several indices show pretty good results, such as Ball-Hall with a value of 1.273672 (the smaller, the better) and Davies-Bouldin (DB) with a value of 0.9971942 (the smaller, the better), indicating that the clusters have good compactness. The Calinski-Harabasz (CH) index is at a value of 686.8874 (the more significant, the better), which indicates a reasonable cluster separation, although it can still be improved. However, the Silhouette value of 0.4002105 and the Xie-Beni value of 665.9598 indicate that the clusters still need to be fully optimal for stronger separation and compactness.

At $k = 3$, the index results show a significant improvement. The Ball-Hall value decreased to 0.936657, which means the clusters became more compact. The CH value skyrocketed to 1 289.818, indicating a much better cluster separation than $k = 2$. Additionally, the DB value decreased to 0.7324939, which indicates better-separated clusters, and the Silhouette increased to 0.4488218, meaning the cluster quality improved. The Xie-Beni index value is also lower at $k = 3$, at 548.9815, indicating that the clusters have better compactness and separation.

From most indices, $k = 3$ is the optimal choice for Euclidean Distance. A higher CH index, a lower DB index, and an increased Silhouette value indicates that the clusters' separation and compactness are better at $k = 3$ than $k = 2$, resulting in more effective and accurate clustering.

2. For the Standardized Euclidean, Standardized Euclidean Robust, Maximum, Manhattan, and Minkowski distances, the majority of indices, such as Ball-Hall, Calinski-Harabasz (CH), Davies-Bouldin (DB), Silhouette, and Xie-Beni, consistently show that $k = 3$ is the optimal solution. Higher CH indices, lower DB indices, and increased Silhouette values across all these metrics indicate better separation and compactness of clusters at $k = 3$, similar to the results found with the Euclidean distance. However, Canberra and Robust Mahalanobis are slightly different, with less optimal results than other distance metrics in choosing $k = 3$, indicating variations that need to be considered in cluster separation.
3. For the Canberra and Mahalanobis distances, the Ball-Hall, Det-ratio, and Silhouette index values yield an optimal k value of $k = 3$. Meanwhile, for the CH, Dunn, and Xie Beni index values, the optimal k value is $k = 2$. Therefore, the optimal value for both distances can be $k = 2$ or $k = 3$.
4. Meanwhile, for the Manhattan distance, based on the majority value of the indices, namely the BH index, Det-Ratio, Dunn, and Xie Benie, the optimal k is $k = 2$.

3.4 Clustering visualization

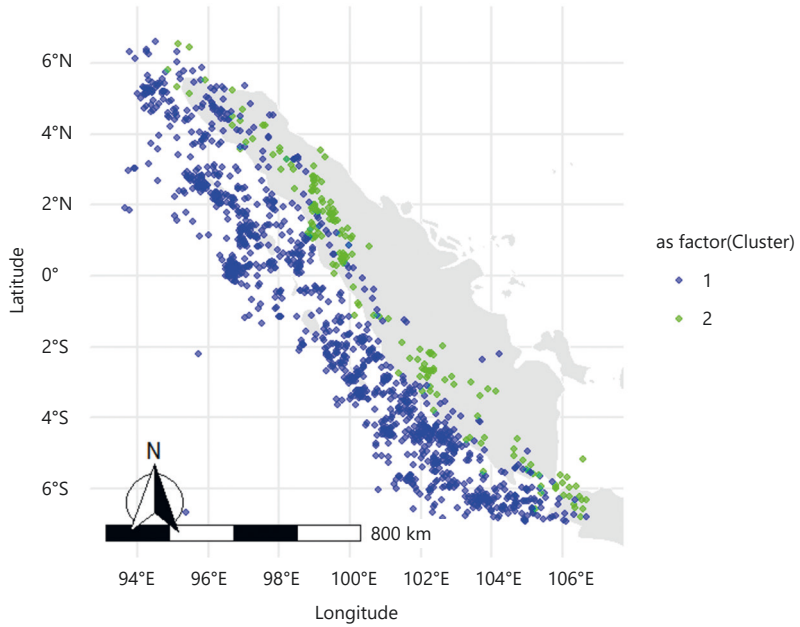
After determining that $k = 2$ and $k = 3$ are the optimal values based on evaluating internal indices using various distance methods, the next step is to display the clustering results for both k values. The clustering visualization results will be used to analyze the characteristics of the formed clusters and evaluate how variations in the number of clusters affect data separation in multidimensional space.

Figure 2 shows the spatial visualization of the clustering results formed for $k = 2$ using the K-means algorithm with the robust, standardized Euclidean distance measure. This visualization identifies distinct spatial patterns between the two clusters based on earthquake magnitude, depth, and spatial distribution variations.

Figure 3 shows the clustering results were shown geographically when $k = 3$ and the K-means algorithm with the robust Mahalanobis distance measure was used. The clustering results indicate more precise distinctions among the three clusters, which will be analyzed further regarding earthquake depth, magnitude, and dispersion patterns. The spatial separation of these clusters enhances the understanding of the geological processes that may be driving the clustering.

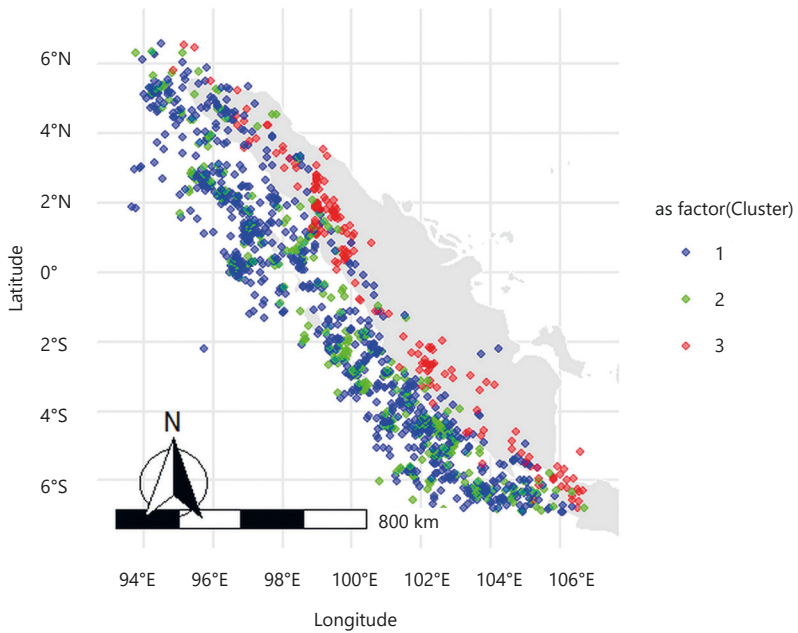
This visualization analysis provides a foundation for further interpretation and discussion of the earthquakes' characteristics in the following chapter.

Figure 2 Result of K-means clustering for $k = 2$ using Standardized Euclidean Robust



Source: Own research

Figure 3 Result of K-means clustering for $k = 3$ using Mahalanobis Robust Distance



Source: Own research

4 DISCUSSION

The analysis considered the earthquake's depth, magnitude, distribution, and implications.

4.1 Analysis of cluster characteristics ($k = 2$)

Earthquakes in Cluster 1 have a much shallower depth, averaging around 33 km, compared to Cluster 2, which has an average depth of 153.7 km. This difference may reflect that the earthquakes in Cluster 1 are closer to the subduction zone or shallow faults around Sumatra, while Cluster 2 is associated with deeper earthquakes, possibly from different tectonic activity or from deeper crustal depths.

The earthquakes in Cluster 1 have a slightly higher average magnitude (4.59 Ms) compared to Cluster 2 (4.40 Ms). Although the difference is small, it suggests that the earthquakes in Cluster 1 may be more destructive due to occurring at shallower depths and with greater magnitude.

Cluster 1 represents more than 85% of all recorded earthquakes, which means that most seismic activity in Sumatra occurs at shallow depths. This is important because shallow earthquakes generally have greater potential to cause structural damage compared to deep earthquakes, whose energy may be absorbed before reaching the surface. Cluster 2, which has deeper earthquakes with lower magnitudes, is likely associated with deeper seismic events in the Earth's crust that are not as hazardous to surface infrastructure.

Based on the analysis results above, using the K-means clustering method based on standardized Euclidean robust distance, two main earthquake clusters in Sumatra have been successfully identified. The first cluster shows shallow earthquakes with slightly larger magnitudes, while the second cluster is more oriented towards deeper earthquakes with lower magnitudes. This has important implications for earthquake risk mitigation, where special attention needs to be given to earthquakes in Cluster 1 as they have the potential to be more destructive.

4.2 Analysis of cluster characteristics ($k = 3$)

The earthquakes in cluster 1 are shallow (about 33 km) with small to moderate magnitudes (around 4.40), indicative of tectonic earthquakes occurring at shallow depths. This cluster comprises 62% of all known earthquakes. Cluster 1 is characterized by shallow earthquakes of low to moderate magnitudes, indicating surface tectonic activity that produces lower-energy seismic events.

Conversely, the earthquakes in cluster 2 indicate a depth similar to that of cluster 1, measuring 34.61 km; nevertheless, this cluster possesses a greater magnitude, around 5.08, compared to the others. Cluster 2 encompasses earthquakes of greater magnitude, representing around 24% of all recorded earthquakes, indicative of greater subduction activity or significant faults that generate more powerful earthquakes, which may be a problem in disaster risk evaluation.

Cluster 3 comprises deep earthquakes (about 155 km) with small to moderate magnitudes. Earthquakes at this depth typically occur in deep subduction zones or plates descending significantly (Benioff zone), resulting in less surface impact. Despite occurring at significant depths, the earthquake's magnitude was minor.

Based on the analysis results above, using the robust Mahalanobis-based K-means clustering method, three main earthquake clusters in Sumatra have been successfully identified. Clusters 1 and 2 are likely related to the earthquakes occurring near the subduction zone, which is the meeting point between the Indo-Australian and Eurasian plates, as well as the Sumatra Fault. These shallow earthquakes may occur in the transitional area between the two tectonic features but the dominance of shallow earthquakes and larger magnitudes in Cluster 2 is likely due to subduction activity. Cluster 3, which consists of deep earthquakes, is most likely directly related to the deep subduction zone, particularly in the Benioff zone. The significantly greater depth of these earthquakes compared to other clusters indicates that they occur due to the movement of plates descending to great depths.

CONCLUSION

Based on the results obtained in this study, robust distance measures, such as Standardized Euclidean Robust and Mahalanobis Robust, effectively handled outliers in seismic data from Sumatra, resulting in more accurate and well-separated clusters. The findings confirmed that these robust approaches consistently outperformed traditional Euclidean distance in clustering accuracy, as demonstrated by various internal evaluation indices.

This study uses K-means cluster analysis with robust metrics like Standardized Euclidean Robust Distance and Mahalanobis Distance to understand where and how earthquakes occur in Sumatra. These metrics effectively accommodate data variation, particularly when handling frequent outliers in seismic data. More representative clusters unaffected by outliers were identified by adopting a robust approach in K-means. This contributes to a better understanding of the tectonic dynamics of the Sumatra region and provides practical implications for disaster risk mitigation. This approach ensures that outliers do not distort the results, leading to a more stable and reliable cluster understanding of seismic patterns.

This study successfully addressed the research objectives, demonstrating that robust distance metrics enhance clustering accuracy and effectively mitigate the impact of outliers. For future research, we recommend further exploration of other robust distance metrics and adaptive clustering algorithms to improve accuracy and robustness in datasets prone to outliers. Extending this approach to high-dimensional and noisy data domains, such as environmental monitoring and market segmentation, could validate its broader applicability. Additionally, dynamic clustering techniques that adaptively update cluster centers based on evolving seismic patterns are suggested to enhance the model's adaptability.

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27th International Conference *Applications of Mathematics and Statistics in Economics (AMSE 2025)*

Stanislava Hronová¹ | *Prague University of Economics and Business, Prague, Czech Republic*

The 27th annual international conference, entitled Applications of Mathematics and Statistics in Economics, was held from 27 to 31 August 2025 in Hradec Králové. The organisation of this year's conference was undertaken by the Departments of Statistics at the Prague University of Economics and Business. The conference was held under the auspices of the President of the Czech Statistical Office, while *Statistika: Statistics and Economy Journal* acted as a conference partner. The conference was attended by over 40 experts from the Czechia, Slovakia, and Poland, including representatives from Matej Bel University in Banská Bystrica, Prague University of Economics and Business, Wrocław University of Economics and Business, University of Pardubice, Czech University of Life Sciences, Slovak Statistical and Demographic Society, the Czech Statistical Office, and the Statistical Office of the Slovak Republic. *Statistika: Statistics and Economy Journal* had a stall at the conference, where conference participants had the opportunity to discuss the conditions and possibilities of prospective publication in the journal with representatives of the editorial board.

The professional programme of the conference was opened by Marek Rojíček, President of the Czech Statistical Office, with a keynote speech entitled *The Future of Demographic Statistics in the Czech Republic*. In this speech, he outlined further possibilities for the development of demographic statistics in connection with the concept of the census. The traditional approach to demographic statistics was based on data from regular censuses, combined with information on the number of births, deaths, marriages, and migrants. In recent decades, only a small number of countries (primarily in Northern Europe) have been able to estimate the size and structure of their populations using administrative sources alone. However, during the previous census cycle, the majority of countries managed to collect data either entirely or at least partially from administrative sources, without the need to conduct this extensive and costly survey. With regard to the situation in the Czechia, the current scope of administrative data sources remains a limiting factor, although it is anticipated that this situation will gradually improve in the coming years. The analysis of so-called "signs of life" will play a key role in this process. The Czech Statistical Office has made notable progress in this area, implementing both legislative and technical measures as part of the 2021 Census.

The conference then proceeded in four sections: *Macroeconomic Issues, Time Series, Cluster Analysis, Social Economics and Statistics, Statistical Methods and History of Statistics*. A new panel discussion

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on the topic of *Teaching Statistics to Non-Statisticians* was added to the conference programme, with representatives from five universities participating as panellists (Ivana Malá from the Prague University of Economics and Business, Tomáš Hlavsa from the Czech University of Life Sciences, Alena Kaščáková from Matej Bel University, David Zapletal from the University of Pardubice, and Albert Gardoň from Wrocław University of Economics and Business), who presented the programmes and methods of teaching statistics to non-statisticians at their universities. The panel featured an engaging discussion that focused particularly on the depth of theoretical teaching, the benefits and importance of addressing practical problems, the integration of various statistical applications into teaching, and, finally, methods for assessing students' knowledge.

From the conference programme, I would like to highlight a selection of contributions that I consider to be of particularly high quality, intellectually engaging, and methodologically innovative.

In the *Macroeconomic Issues* section, the most notable contribution was *The Impact of Media on Inflation Expectations in V4 Countries*. The authors (Peter Laco, Žaneta Lacová and Timotej Šagúl) presented the results of the research team's work, which examined how different types of news influence inflation expectations across various demographic groups in the V4 countries. The study was based on the assumption that traditional media primarily shape the outlook of older cohorts, while online social networks are more in line with the expectations of younger and more educated individuals. It further posits that media-induced effects can persist for more than a year, highlighting the importance of historical inflation trends and the gradual absorption of new economic information. Granger causality tests were used in the analysis.

The conference paper of Karolína Bakuncová and Luboš Marek on the topic of *Dimensionality Reduction Methods for Clustering Using Signal Analysis* in the *Time Series and Cluster Analysis* section attracted a well-deserved attention of the conference participants. The authors presented the possibilities of improving clustering efficiency through dimensionality reduction using signal processing techniques, namely the Discrete Fourier Transform (DFT), Discrete Wavelet Transform (DWT), and Discrete Cosine Transform (DCT). DFT serves as a fundamental building block for many other signal analysis methods, while DWT and DCT are improvements over DFT both in flexibility and computational efficiency. For the clustering itself, hierarchical clustering with complete linkage was employed. The proposed approach was tested on three datasets of varying sizes from the UCR Archive. Results showed that signal-based representations significantly reduce computation time and, in most cases, provide comparable or even improved clustering results compared to clustering on the original data.

The issue of population ageing was addressed in the *Social Economics and Statistics* section through a contribution titled *Europe's Silver Well-being Map: Where Does Old Age Taste the Sweetest?*, authored by Joanna Debicka, Ahata Girul and Edyta Mazurek. The authors emphasised that, in the context of the ever-increasing proportion of senior citizens, quality of life in old age is no longer merely a personal matter – it is becoming a measure of social maturity, institutional efficiency and the ability of society to respond to the needs of its most experienced members. The authors presented the results of a comparative analysis of the living conditions of older adults across the European Union. Data from the EU-SILC survey and various well-being indicators assess which countries offer the most favourable environments for older people in terms of material wealth, health, social inclusion, subjective well-being and institutional support. Particular attention was paid to public policy practices that contribute to high well-being of seniors. The analysis pointed to countries that act as role models in the field of ageing policies – Belgium, the Netherlands, Finland, Sweden, Ireland and – somewhat unexpectedly – Poland, suggesting the effectiveness of selected local and national initiatives. The findings show that it is possible to build age-friendly societies, where aging does not mean marginalisation, but rather an integrated and valuable part of sustainable social development.

The potential applications of web scraping in the context of data collection on rental prices from Czech real estate portals were explored in the section dedicated to *Statistical Methods* in a paper entitled *Imputation and Weighting of Observations Based on Spatial Dependence in Constructing a Point Estimate of Prices of Rents in Cadastral Areas of Prague*, authored by Adam Slavíček. A spatial dependency analysis was performed on the obtained data, on the basis of which a data imputation algorithm was designed for calculating the price level in cadastral areas with a low number of observations from neighbouring cadastral areas. The imputed observations are assigned weights based on their distance from the centroid of the area, in order to maintain the consistency of spatial relationships. The procedure thus contributes to the methodological framework for analysing the real estate market using spatial data and machine learning.

It has been a long-standing tradition at the AMSE conference that the final presentation is dedicated to the history of statistics. On this occasion, the authors, Prokop Závodský and Ondřej Šimpach, addressed the subject of *250 Years of Teaching Statistics at the University of Prague*. The authors focused on Josef Mader, professor of statistics in the years 1779–1815, author of the theoretically focused publication “Ueber Begriff und Lehrart der Statistik” (1793) and a number of contributions in the proceedings published by the Masonic group around J. A. Riegger (a total of 15 volumes in the years 1787–1795).

The complete AMSE 2025 programme, including abstracts of the presented contributions, can be found at: <<http://www.amse-conference.eu>>. The site also contains information about the history of AMSE and links to previous editions of this international conference.²

In accordance with the established tradition of alternating between the three countries (Slovakia – Poland – Czechia), the 28th AMSE conference will be hosted by colleagues from the Department of Statistics at Matej Bel University in Banská Bystrica. The event is scheduled to take place in Martin, Slovakia, at the end of August 2026.

² In this report on the conference, the texts of the Book of Abstracts were used – accessible via the following link: <www.amse-conference.eu>.

33rd International Conference *Interdisciplinary Information Management Talks (IDIMT 2025)*

Petr Doucek¹ | *Prague University of Economics and Business, Prague, Czech Republic*

Lea Nedomová² | *Prague University of Economics and Business, Prague, Czech Republic*

The Interdisciplinary Information Management Talks (IDIMT)³ conference is traditionally organized by the Department of Systems Analysis of the Faculty of Informatics and Statistics at the Prague University of Economics and Business, in co-operation with Johannes Kepler University Linz. This year, staff from the Faculty of Business Administration at the University of Economics in Bratislava, Košice campus, also participated in its implementation. The proceedings of this year's 33rd conference, which took place from September 3 to 5 in Hradec Králové, were held under the umbrella title "ICT in Business: AI Everywhere? Glory and Disgrace of AI." The entire conference was divided into a total of ten sections, one of which was dedicated to presentations by doctoral students who are starting their academic careers. We have chosen the following topics for the IDIMT 2025 conference:

- AI in Crisis management,
- Cyber Security vs AI,
- Ethical Aspects of AI: Research and Usage,
- Data, AI and Digital-Driven Transformation: Shaping Sustainable Digital Futures
- AI and Autonomous Systems,
- Business Information Systems and Digitalization,
- Social Media and AI: Contributor, Selector, ...?
- AI in Supply Chain management,
- University-Industry Collaboration,
- Special doctoral session: Early Career & Student Showcase.

As the overall title of the conference suggests, one of its most important topics was artificial intelligence and its potential and actual use in everyday economic and academic life – not only its advantages, but also its risks and problems. This topic was also the core of the opening panel discussion following the ceremonial opening of the conference by Michael Sonntag from Johannes Kepler University in Linz. During the discussion, invited guests from Slovenia, Austria, Slovakia, and the Czech Republic exchanged views not only on the possible applications of artificial intelligence in practical computer science for business applications, but also on its use to improve the quality of educational and scientific work. In addition to positive views on the future of business informatics under the baton of artificial intelligence, there were also critical opinions that assessed emerging risks, such as the possibility of high-quality plagiarism without creative potential of authors, especially in the field of scientific and research activities.

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³ More at: <<https://idimt.org>>.

The panel discussion was followed by a section entitled “Special doctoral session: Early Career & Student Showcase,” which offered presentations by doctoral students on topics related to their dissertations. For many of them, this was their first international appearance in a friendly environment, where they had the opportunity to present and defend the results of their work and receive feedback from experts from the international forum.

The conference participants showed great interest in the discussions in the individual sections. Among the traditionally high-quality sections were those devoted to cyber security and the ethical aspects of information technology related to the use of information technologies and their deployment at a time of growing importance of artificial intelligence. The section on “AI in Crisis Management” was particularly well attended and focused on the highly topical issue of crisis management and the application of information technology and artificial intelligence in this field. Employees of AGES (Austrian Agency for Health and Food Safety), AIT Austrian Institute of Technology, and Johanniter Austria Training and Research Non-Profit Ltd. demonstrated in their traditionally well-prepared presentations the possibility of protecting human lives and values in crisis situations using computer technology and artificial intelligence. Two sections were devoted to classic applications of information systems in business practice: “AI in Supply Chain Management,” led by colleagues from the Faculty of Business and Economics at the University of Košice, and “Data, AI and Digital-Driven Transformation: Shaping Sustainable Digital Futures,” led by colleagues from the University of Maribor in Slovenia.

As a result of the conference, besides the presented results of the scientific work, the collaboration between Prague University of Economics and Business, Johannes Kepler University Linz, Bratislava University of Economics and Business and other universities and research institutions from Austria, Slovakia, and Slovenia, which were represented in the wide plenary of participants, was deepened.

This conference was partially co-funded through project IGA 409035 of the Faculty of Informatics and Statistics, Prague University of Economics and Business, and Johannes Kepler University Linz, Austria.

We will therefore look forward again to the next IDIMT conference to see what new issues it will bring. The event will traditionally take place in Hradec Králové in September 2026.

43rd International Conference on *Mathematical Methods in Economics (MME 2025)*

Ondřej Sokol¹ | Prague University of Economics and Business, Prague, Czech Republic

The 43rd International Conference on Mathematical Methods in Economics took place at Tomas Bata University in Zlín from September 3 to 5. This annual event serves as a traditional meeting point for academics and professionals from both universities and industry who share an interest in the theory and applications of operations research and econometrics.²

The conference was organized by a team from Tomas Bata University, led by Dušan Hrabec and David Tuček, in cooperation with the Czech Society for Operations Research.

This year's conference received over 70 submissions and welcomed more than 80 active in-person participants from countries including the Czech Republic, Slovakia, Norway, and China. Accepted peer-reviewed papers were published in the *Proceedings of the MME 2025*.

The event opened with three invited lectures. The first was delivered by Professor Stein W. Wallace from the Department of Business and Management Science at NHH Norwegian School of Economics, a renowned expert in stochastic programming. His talk focused on situations where standard deterministic optimization models fall short, necessitating the use of stochastic programming.

The second invited speaker was Professor Milan Hladík from the Department of Applied Mathematics at the Faculty of Mathematics and Physics, Charles University. He discussed interval linear programming and its applications across various domains.

The final invited lecture was given by Tomáš Pajonk, a graduate of the Faculty of Informatics and Statistics at the Prague University of Economics and Business, and currently the owner and senior developer at Solvertch, a company specializing in transportation planning optimization. His presentation highlighted practical challenges the company addresses, primarily various forms of the vehicle routing problem, along with the standard transportation problem. His presentation brought a welcome dose of practical insight to a conference largely centered on theoretical topics.

As per tradition, the conference featured a PhD student competition sponsored by the Czech Society for Operations Research, offering a prize of 10 000 czk. This year's winner was Jakub Neugebauer from the Prague University of Economics and Business, recognized for his paper titled *A Vector-Based Weight Adjustment Algorithm for Portfolio Optimization Boosting Genetic Algorithm Efficiency*. Second place also went to the Prague University of Economics and Business, awarded to Petr Krautwurm for his paper *Revisiting the Almost Ideal Demand System with Respect to Substitutability and Complementarity: Suitability for Simulating Consumer Behavior*. Third place was claimed by Erik Kočandrl from the Faculty of Mathematics and Physics at Charles University, for his work *Mean-CVaR Portfolio Choice Problem With Endogenous Randomness*.

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² More at: <https://mme2025.utb.cz>.

In addition to the standard sections, a new segment titled *Discussion Table* was introduced at the MME conference. This interactive forum brought together academics and industry professionals to exchange insights and best practices on teaching the Data Envelopment Analysis (DEA) methodology and designing robust DEA models for high-quality efficiency assessments.

The conference program also included guided tours to iconic landmarks of Zlín's Baťa heritage, including the Baťa Institutes and the Baťa Skyscraper, known for its unique office elevator – a spacious 6×6 meter cabin that once served as the mobile office of the company's director. The conference dinner, accompanied by live music, was held at the historic Baťa Villa, where participants also had the opportunity to join a guided tour.

The next edition, the 44th MME Conference, is scheduled to take place at Vysoká škola báňská – Technical University of Ostrava from 9 to 11 September 2026.

19th Year of the *International Days of Statistics and Economics (MSED 2025)*

Tomáš Löster¹ | *Prague University of Economics and Business, Prague, Czech Republic*

From 4th to 5th September 2025, a worldwide conference of the International Days of Statistics and Economics (MSED) took place at the Prague University of Economics and Business. The conference belongs to traditional professional events; this year, the sixteenth year of this event was held. Prague University of Economics and Business (the Department of Statistics and Probability and the Department of Managerial Economics) was the main organizer, as usual; and was helped by the Faculty of Economics, the Technical University of Košice, and Ton Duc Thang University, as co-organizers. The conference ranks among important statistical and economic conferences, which can be proved by the fact that Online Conference Proceedings were included in the Conference Proceedings Citation Index (CPCI), which has been integrated within the Web of Science, Clarivate Analytics since 2011.

The traditional goal of this international scientific conference was a presentation of the contributions of individual authors and a discussion of current issues in the field of statistics, demography, economics, and management and their interconnection.

This year's conference and presentation were again in a hybrid form (online and real presentation at the university), which caused the participation of foreign nationals to be active.

The online implementation of the conference took place in individual channels of the conference teams in MS Teams (according to partial sections). The number of registered conference participants was a total of 98, of which 49 were foreign, e.g. Turkey, Slovakia, Vietnam, etc. Among the conference participants were 18 doctoral students.

The received papers were first evaluated in terms of scientific content and suitability of the topic concerning the focus of the conference. After the exclusion of unsatisfactory abstracts, a double independent anonymous review procedure took place in the spring of this year.

We would also like to invite researchers, doctoral students, and the wide professional public to the twentieth International Days of Statistics and Economics, which will take place at the Prague University of Economics and Business traditionally in early September 2026.

More at: <<http://msed.vse.cz>>.

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We publish articles focused at theoretical and applied statistics, mathematical and statistical methods, conception of official (state) statistics, statistical education, applied economics and econometrics, economic, social and environmental analyses, economic indicators, social and environmental issues in terms of statistics or economics, and regional development issues.

The journal of *Statistika* has following **sections**:

The **Analyses** section publishes complex and advanced analyses based on the official statistics data focused on economic, environmental, social and other topics. Papers shall have up to 22 pages (Times, 1.5-spaced pages).

Discussion brings the opportunity to openly discuss the current or more general statistical or economic issues, in short what the authors would like to contribute to the scientific debate. Discussion shall have up to 10 pages (Times, 1.5-spaced pages).

In the **Methodology** section we publish articles dealing with possible approaches and methods of researching and exploring social, economic, environmental and other phenomena or indicators. Articles shall have up to 22 pages (Times, 1.5-spaced pages).

Consultation contains papers focused primarily on new perspectives or innovative approaches in statistics or economics about which the authors would like to inform the professional public. Consultation shall have up to 10 pages (Times, 1.5-spaced pages).

Book Review evaluates selected titles of recent books from the official statistics field. Reviews shall have 2 pages (Times, 1.5-spaced pages).

Information section contains informative (descriptive) texts, latest publications, or recent and upcoming scientific conferences. Recommended range of information is 10 pages (Times, 1.5-spaced pages).

Language

The submission language is English only. Authors are expected to refer to a native language speaker in case they are not sure of language quality of their papers.

Recommended paper structure

Title – Abstract and contacts – Abstract (max. 160 words)
Keywords (max. 6 words / phrases) – Introduction – 1 Literature survey – 2 Methods – 3 Results – 4 Discussion – Conclusion – (Acknowledgments) – References – (Annex/Appendix).
Tables and figures (for the review process shall be placed in the text)

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Main text format

Times 12 (main text), 1.5 spacing between lines. Page numbers in the lower right-hand corner. *Italics* can be used in the text if necessary. Do not use **bold** or underline in the text. Paper parts numbering: 1, 1.1, 1.2, etc.

Headings

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Footnotes

Footnotes should be used sparingly. Do not use endnotes. Do not use footnotes for citing references.

References in the text

Place references in the text enclosing authors' names and the year of the reference, e.g.,... White (2009) points out that...", "...recent literature (Atkinson and Black, 2010a, 2010b, 2011; Chase et al., 2011: 12–14) conclude...". Note the use of alphabetical order. Between the names of two authors please insert „and”, for more authors we recommend to put „et al.”. Include page numbers if appropriate.

List of references

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