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Macroeconomic performance of European Union's small open economies during the COVID-19 pandemic

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Abstract

This paper explains the business cycle characteristics in the small open European Union Countries during the COVID-19 pandemic. The panel cyclical components of GDP and its components, labour, and average product of labour were computed. The study adopts a real business cycle model with importable, exportable, and tradeable products to explain the cyclical characteristics of small and big EU countries. According to the results, the business cycle characteristics of the big EU countries during the pandemic correspond to the findings from the papers worldwide. The primary shock was a decrease in the labour supply. An increase in the adjustment capital costs explains the unusual consumption volatility. Results related to the small EU countries differ from those of the big countries and those obtained in other studies. The primary source of macroeconomic changes during the pandemic was changes in the terms of trade. Changes in the labour supply were also significant. The higher capital adjustment costs explain the consumption volatility, and the higher debt service costs explain the investment volatility.

Keywords COVID-19 pandemic · European Union · Small economies · Business cycle · MXN model

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1 Introduction

The COVID-19 pandemic and the corresponding political regulations caused a global economic crisis of unprecedented scale. The outbreak of the pandemic in Europe and the Western world occurred in the second quarter of 2020. Shortly after the pandemic outbreak, many scientific papers appeared worldwide identifying the main macroeconomic shocks associated with the crisis and their short-term and long-term consequences.

World studies dealing mainly with the impact of the pandemic on large economies assume that the main shock associated with the pandemic is a decrease in labour (see Literature review in the second chapter). During global crises, the responses of small open economies often diverge from those of their larger counterparts, whose data typically dominate most analyses. The project Dück et al. (2022) summarises analyses based on microeconomic principles. This paper aims to extend the knowledge gained by these works to the characteristics of pandemic responses in small open economies common in the European Union.

Trade shocks, in particular, wield significant influence in small, open countries, which are also more susceptible to financial frictions. This paper will demonstrate that these characteristics persist even during a pandemic crisis. In addition to the extensive global analyses of the macroeconomic aspects of the pandemic crisis, there is a need for more in-depth examinations of the cyclical characteristics of small open economies during such crises. Crucially, questions about the unique shocks that the pandemic crisis presents to small open economies still need to be answered. Due to the pandemic, are small European countries grappling with higher debt costs, investment costs, and risks than their larger counterparts?

This paper aims to explain the cyclical characteristics of the European Union's small open economies during the COVID-19 pandemic. The third chapter, which focuses on the data used, presents the cyclical characteristics through the moments of the cyclical components of GDP, its components, and the terms of trade and labour. Different data filters calculate the cyclical components. We are particularly interested in the standard deviation, correlation matrix, and serial correlation rate of cyclical components in the small countries of the European Union during the pandemic period. These values will be compared with the values in the regular period in the European Union and with the values of the large countries of the European Union during the pandemic period. The chapter also provides detailed information on the data needed to calibrate the theoretical model so that the steady state corresponds to the long-term characteristics of international trade in the studied countries. The choice of an adequate model resulted from the results presented in the chapter (moments of cyclical components). Therefore, the data chapter precedes the chapter describing the model.

Uribe and Schmitt-Grohé (2017) proposed a model to explain business cycles in small open economies. The model distinguishes between the production of importable (M), exportable (X) and non-tradable (N) goods (MXN model). The next chapter presents the model. An importable good is either imported

or produced domestically but is highly substitutable with a good that can be imported. An exportable good is either exported or a sold domestically but is highly substitutable with a good that can be exported. Unlike most pandemic macroeconomic models, the SIR model is not used to simulate a pandemic outbreak. It is assumed that the pandemic and the corresponding distancing policy affect the labour supply and demand, consumption demand, total factor productivity, terms of trade, adjustment investment costs and debt service costs. Therefore, adjusting the model by the parameters shifting the labour supply and demand and consumption demand is necessary. The pandemic outbreak is realised by a universal shock that impacts these parameters, the total factor productivity and the terms of trade. The values of these parameters are calibrated to match the pandemic cyclical characteristics calculated in the third chapter of the paper. Even before that, the values of the other parameters must be calibrated so that the model's steady state corresponds to the long-term characteristics of the studied countries derived from the available international trade data.

The study results from calibrating the business cycles of the studied countries during the pandemic are presented in the following chapters. These chapters provide a detailed analysis of the results and a corresponding discussion, culminating in the final chapter, which draws the paper to a close with a comprehensive conclusion.

2 Literature review

In their project, Dück et al. (2022) collected the most important works that used mathematical dynamic models based on microeconomic principles to analyse macroeconomic responses to the pandemic and the corresponding policy responses. These models, known as dynamic stochastic general equilibrium models (DSGE), play a crucial role in understanding the pandemic's macroeconomic impacts. Most papers use the mutual simultaneous connection of a pandemic SIR (Suspected, Infected, and Recovered) model introduced by Kermack and McKendrick (1927) and re-introduced by Atkeson (2020) with a macroeconomic model. The main shock causing the crisis is the decline in labour supply, primarily due to frequent illnesses and deaths, but mainly distance restrictions, thanks to limited work activity, mainly in industries requiring personal interaction. According to the proposals of some authors (Cardani et al. 2022; Eichenbaum et al. 2022b; Lepetit and Fuentes-Albero 2022; Crucini and O'Flaherty 2020; Eichenbaum et al. 2021), the shock of the decrease in consumer demand is also significant, which can explain the unusually excessive reaction of consumption compared to the reaction of investments.

In our later paper (Szomolányi et al. 2023), we proposed that financial market frictions cause unusual volatility in consumption and investment during pandemics. Some papers consider the friction in financial markets. Vo et al. (2022) found that, on average, firms tend to adjust their capital structure more rapidly in the period following the breakout of COVID-19. Financial frictions are essential to the new Keynesian DSGE model, which Acurio Vásconez et al. (2023) used to evaluate unconventional monetary policy. The MXN model of Uribe and Schmitt-Grohé (2017) presented in the fourth chapter will, after our modifications, include the

consumption demand reaction to a pandemic shock and the possibility of modifying adjustment capital and debt service costs representing the market frictions.

World research provides detailed answers to vital questions about the pandemic's macroeconomic impacts and the corresponding restrictive policies (Cardani et al. 2022). Some papers evaluate various public policy strategies to stop the pandemic's spread with minimal economic disruptions (Bodenstein et al. 2022; Eichenbaum et al. 2022c; Krüger et al. 2020; Garcia-Vicuña et al. 2022; Angelov et al. 2023; Kuvvetli 2023). Moser and Yared (2022) consider aspects of time consistency of public pandemic policy. Some papers analyse the fiscal (Faria-e-Castro 2021; Eichenbaum et al. 2022a; Chopra et al. 2022; Crucini and O'Flaherty 2020; Eichenbaum et al. 2021) and monetary (Brzoza-Brzezina et al. 2022; Eichenbaum et al. 2022b; Lepetit and Fuentes-Albero 2022) policy reactions during the pandemic period. Other papers deal with international economic interaction regarding the spread of the pandemic. Acharya et al. (2022) aim to determine optimal pandemic containment policies when the governments of the two countries do not coordinate (Nash equilibrium) and when both governments coordinate (risk-sharing equilibrium). Rubini (2020) evaluates the effects of COVID-19 across countries by extending a canonical SIR model with various countries' parameter values.

Fewer works answer the question of the pandemic responses of small open economies. At the same time, small countries' usual cyclical behaviour is often subject to shocks resulting from their dependence on the surrounding world, and trade shocks are a frequent source of economic fluctuations. Garcia et al. (2023) and Böschemeier and Mau (2023) confirm the statement. Calibrating the various versions of their model for Ireland, Luxembourg, the Netherlands and Slovenia, Garcia et al. (2023) showed that a very significant fraction of the 2020 decline in economic activity in those small open economies resulted from foreign factors related to either trade or fiscal policies. Böschemeier and Mau (2023) used econometric research to confirm that about half of the total import contraction is attributed to foreign supply-side disruptions.

3 Data

The study uses a panel data structure for 27 European Union countries (EU27). We consider Germany, Spain, France, Italy and Poland to be large countries, and Belgium, Bulgaria, the Czech Republic, Denmark, Estonia, Ireland, Greece, Croatia, Cyprus, Lithuania, Latvia, Luxembourg, Hungary, Malta, Austria, Portugal, Slovenia, Slovakia, Finland and Sweden to be small countries. We do not classify the Netherlands and Romania as large or small countries. Based on the work of Uribe and Schmitt-Grohé (2017) (whose model we modified), the global classification of countries used in our study distinguishes large, medium and small countries by population. When we apply analogous classification to the European Union, we find a significant number of tiny countries (up to 12 million) and a small group of large countries (over 35 million). To distinguish their cyclical characteristics, we decided to create only two groups. The group of medium-sized countries consists of only two states, Romania and the Netherlands, which is not enough to examine the

cyclical characteristics. However, from the perspective of our paper's focus on European small open economies, this classification is sufficient for our purposes.

Data characterising cyclical characteristics in the European Union's countries are GDP and its components, terms of trade, and hours worked at a quarterly frequency. Cyclical components were calculated from these data, expressing cyclical characteristics in the examined countries in the whole time sample and during the pandemic, with a distinction between small and large European countries.

The quarterly panel data includes GDP, consumption, investment, exports, imports, and labour. Labour is measured in the number of hours worked. From the data, we computed the net exports (the trade balance) as the difference between exports and imports; the average product of labour (labour productivity)[1] is the share of GDP and labour. We obtained all available data of the EU27 countries from the first quarter of 1995 to the fourth quarter of 2022 from the Eurostat (2023) database. In the database, data on the GDP components of the Czech Republic, Italy and the Netherlands are only available from the first quarter of 1996, and data on hours worked are only available from the first quarter of 2009.

The available data of GDP components are seasonally and calendar-adjusted; labour is seasonally adjusted. At the time of the paper's completion, hourly labour data in Germany in 2020 was not available. Therefore, we used the time series of all working people for the German labour.

The following is a calculation of the cyclical components of the time series. Different papers prefer different methods. With the following robust analysis, we adopt the arguments of Uribe and Schmitt-Grohé (2017), according to which, in the analysis result, the critical moment ratios do not differ depending on the choice of different methods. The authors also applied a similar analysis (Szomolányi et al. 2017). We used the Hodrick and Prescott filter (1997) (HP) with the lambda parameter for quarterly data set to 1600 by default to calculate the cyclical components. Flaig (2015) remarks that "it is well known that the HP filter is an optimal filter under some restrictive assumptions, especially that the cycle is white noise", as in our case. He showed that the HP filter with a much higher smoothing parameter than commonly used is preferred for the autocorrelated cyclical components. In our analysis, the low autocorrelation coefficient is computed during the pandemic period.

Before the calculation, we logarithmised all time series besides net exports, which we divided by the trend component of output. We calculated the standard deviations, the correlation coefficient with the series of the cyclical component of GDP and the autocorrelation coefficients (ser. corr.) of the series. Table 1 calculates the moments of various samples of the examined panel data cyclical components. In addition, we calculated the given moments of the cyclical components of the studied time series using various other methods. Calculations for small and big countries during the pandemic are in the Appendix, Table 5. Hamilton (2018) states that the HP filter produces series with spurious dynamic relations that have no basis in the underlying data-generating process; filtered values at the end of the sample are very different

[1] In common economic discourse, the concept of labour productivity is often used. Macroeconomic models distinguish between immeasurable (labour or capital) factor productivity and average factor product, which is measured as the ratio of output to input. This is why we also employ this term in our paper.

Table 1 Cyclical characteristics of the EU countries

		GDP	Cons	Inv	Lab	Aver. prod. of lab	Net exp
The whole sample	Std. Devs	2.69%	3.03%	11.94%	2.93%	2.19%	3.55%
	Cor. w. GDP	1.00	0.82	0.41	0.62	0.21	0.05
	Ser. Cor	0.62	0.55	0.22	0.29	0.27	0.15
Pandemic Period	Std. Devs	4.40%	5.05%	12.30%	6.39%	4.24%	3.72%
	Cor. w. GDP	1.00	0.79	0.33	0.75	−0.09	0.26
	Ser. Cor	−0.13	−0.38	−0.08	−0.21	0.03	−0.07
Big countries in the pandemic period	Std. Devs	5.44%	5.63%	8.44%	7.94%	3.42%	1.19%
	Cor. w. GDP	1.00	0.93	0.65	0.94	−0.59	0.64
	Ser. Cor	−0.24	−0.42	0.18	−0.09	0.02	0.34
Small countries in the pandemic period	Std. Devs	4.25%	5.06%	13.42%	6.15%	4.48%	4.27%
	Cor. w. GDP	1.00	0.74	0.27	0.69	0.01	0.25
	Ser. Cor	−0.09	−0.35	−0.13	−0.28	0.01	−0.07

Eurostat (2023), https://ec.europa.eu/eurostat and own processing

from those in the middle and are also characterised by spurious dynamics; a statistical formalisation of the problem typically produces values for the smoothing parameter vastly at odds with standard practice. The parameters of the proposed Hamilton filter are a time horizon that we are likely to predict incorrectly (h) and a number of lags in filter regression (p), H(h,p). For seasonal data, p and h should be integer multiples of the number of observations in a year. For quarterly data, $h=8$ and $p=4$ are recommended. When p is not included, a random walk process is assumed. Hamilton suggests $h=5$ if a debt cycle described by Jorda et al. (2017) is supposed. The generalised band-pass filter is a Christiano-Fitzgerald (2003) filter (CF) with an assumed business cycle length of 6–32 quarters.

The results in the first panel from the top in Table 1 correspond to the total data sample, the second to the pandemic period sample, the third to the large countries during the pandemic period sample, and the fourth to the small countries during the pandemic period sample.

The total data sample results (the first three lines under the heading in Table 1) do not deviate from standard cyclical observations (Uribe and Schmitt-Grohé 2017). Consumption and investment are more volatile than GDP. The high consumption volatility corresponds to the fact that the EU27 consists of many small open countries. As the size of the countries does not weigh the data, the importance of small countries in the result is more significant than it is actually. The components of GDP and labour are positively correlated with GDP. Compared with other studies (Uribe and Schmitt-Grohé 2017), the relatively low value of the correlation coefficient of investment corresponds to the fact that private and public investments are included in investment in the European national accounting system. The value of the correlation coefficient of the average product of labour and GDP is surprisingly low.

The pandemic corresponds to higher economic (GDP) volatility, but the share of investment and GDP volatilities is smaller than in the total data sample. Frequent changes in political and social restrictions can explain high economic volatility. It is

also associated with the cyclical components' low to negative serial correlation coefficient. The correlation coefficient between the average product of labour and GDP was lower during the pandemic than in the entire period.

We also performed moment calculations for big and small EU27 countries. In big countries, investment was even less volatile during the pandemic period. The average product of labour was negatively correlated with GDP. Interestingly, the economic volatility of small countries was lower than in big countries. Conversely, investment was highly volatile in small countries. The investment/GDP volatility ratio was similar to that in the total period sample. The serial correlation coefficient of investment was the lowest in the sample of small countries during the pandemic period.

Similar results also result from the cyclic components calculated by other methods. The differences are in the estimation of the total economic volatility. According to the results, small countries were less volatile in the pandemic than large ones. According to the H(8,4), H(5,4) and CF, this proportion was approximately the same. In small countries, the share of volatilities of consumption and output was approximately 1.1 times. According to the HP filter, this ratio was approximately 1.2, and according to the CF filter, approximately 1. In big countries, this proportion was 1–1.05 (the CF filter calculates it at 0.9). The volatility of investments in small countries was approximately three times that of output. All data filtering methods confirm the unusual volatility of investments in large countries during the pandemic period. The ratio to output volatility is estimated to be only 1.4–1.8. Labour is weakly positively correlated with output in small countries while firmly in large ones. This results in a low but positive correlation between the average product of labour and output in small countries and a stronger negative correlation in large ones. The trade balance is more positively correlated in large countries than in small ones.

A model explaining the economic impacts of the COVID-19 pandemic and the corresponding policy responses in EU27 countries should correspond to the moment values from this analysis. The construction of the model should consider these facts observed in the pandemic period.

The correlation coefficient of the average product of labour with GDP is low or negative. A likely explanation for this observation is that the shock of the pandemic outbreak is associated with frequent changes in labour demand and supply. The risk of the pandemic's spread and restrictive political reactions limited the possibilities of carrying out regular business and work activities.

Investment, compared to GDP, is low volatile. The peculiarity of investment behaviour in pandemics was already noticed by Eichenbaum et al. (2022b), who pointed out that in the first wave of the pandemic, investment fell by about the same amount as GDP and consumption, a shallow fall compared to other economic crises. The authors explained this fact by reducing consumption. The reduction in consumption also results from the high risk of the spread of the pandemic and restrictive political reactions. Cardani et al. (2022); Eichenbaum et al. (2022b); Lepetit and Fuentes-Albero (2022); Crucini and O'Flaherty (2020); Eichenbaum et al. (2021) consider a decrease in the consumption demand as a reaction on the pandemic.

Economic performance during the pandemic was different in small and large countries. In small countries, on the other hand, investment was highly volatile. Such a result corresponds to the normal non-pandemic cyclical behaviour of small economies. It can be concluded that during the pandemic, small economies faced shocks similar to those in other periods. A frequent source of economic volatility is shocks in terms of trade (the share of export and import prices), which are interpreted as trade shocks in current macroeconomic models. Therefore, we conclude that the economic reactions of the population and restrictive measures such as closures of factories, causing supply chain disruptions in small countries, were manifested not only by a reduction in labour, total factor productivity, and consumer demand but also by the mentioned trade shock. It makes sense to examine the shocks associated with the outbreak of the pandemic in the small open economies of the European Union.

Most similar analyses of the impacts of the COVID-19 pandemic so far have focused on the reactions of macroeconomic indicators in different waves of the pandemic in economies of global importance. The advantage of examining data in the European Union countries is that each country has separate economic statistics. This contribution brought a systematic statistical view of macroeconomic principles characteristic of the short pandemic period.

Despite the mentioned data deficiencies, some crucial facts characteristic of the pandemic period in the EU27 countries can be roughly deduced from the results. The pandemic manifested increased economic volatility in the European Union, but the investment was unusually less volatile than in the standard period. The average product of labour and the wage rate were negatively correlated with GDP. The performance of small and large EU27 economies varied. Investment volatility was high in small economies.

These results form an essential starting point for constructing the DSGE model, which can explain the observed facts in the pandemic period in the EU27 economies. The following chapters focus on constructing and verifying the MXN model (Uribe and Schmitt-Grohé 2017), in which pandemic shocks are formulated by a joint shock affecting labour demand and supply, consumption and world price relations. The model allows for setting various parameters for investment adjustment and debt service costs.

4 Model

To analyse the impact of shocks in small open economies, a model that can quantify the impact of shifts in the terms of trade should be chosen. This impact varies according to the share of production of exportable, importable and non-tradable goods. We consider the MXN model proposed by Uribe and Schmitt-Grohé (2017) to be such a model. In the first part of the chapter, we briefly introduce the model. In the next section, we present our modifications of the model that correspond to the reactions of economies to the shock caused by the pandemic and the subsequent distancing policy.

The model studies interactions between households and firms. We assume that a large number of identical households is present. The firms produce final, tradeable composite goods and importable, exportable, and nontradeable goods. To simplify notation, let us create a notation for the first partial derivatives in the sense:

$$f_{\mathrm{i}}(\mathrm{x}) = \frac{\partial f_i(\mathbf{x})}{\partial x_i}$$

where $\mathbf{x}$ is a vector with size n, $\mathbf{x} = \left(x_1, x_2, \ldots, x_n\right)$.

We present the model in a general form. The specific functional forms are adopted from the Uribe and Schmitt-Grohé (2017).

4.1 Households

The following utility function form expresses the households' preferences.

$$\mathrm{M} = \max_{\{c_t, h_t^m, h_t^x, h_t^n\}_0^\infty} \sum\nolimits_{t=0}^{\infty} E_0 \beta^t U\left(c_t, h_t^m, h_t^x, h_t^n\right), \tag{1}$$

where h_t^m, h_t^x, and h_t^n denote labour in the importable, exportable, and nontradeable sectors; c_t is consumption, β is the discount factor, and E_0 means expectations according to the information set available at time 0. The time is denoted by subscript t. The specific function form assumes the constant degree of relative risk aversion σ, and its reciprocal, $1/\sigma$, measures the intertemporal elasticity of substitution. The utility function form (1) corresponds to the GHH (named after the authors' surnames) proposition of preferences (Greenwood et al. 1988). According to the form, the sectors' labour supply (the marginal rate of substitution between consumption and leisure) is independent of consumption. The wage elasticity of the jth sector's labour supply equals $1/\left(\omega_j - 1\right)$; $\omega_j > 0$.

The households' budget constraint is:

$$\begin{aligned} & c_t + i_t^m + i_t^x + i_t^n + \Phi_m\left(k_{t+1}^m - k_t^m\right) + \Phi_x\left(k_{t+1}^x - k_t^x\right) + \Phi_n\left(k_{t+1}^n - k_t^n\right) + p_t^\tau d_t \\ & = \frac{p_t^\tau d_{t+1}}{1 + r_t} + w_t^m h_t^m + w_t^x h_t^x + w_t^n h_t^n + u_t^m k_t^m + u_t^x k_t^x + u_t^n k_t^n, \end{aligned} \tag{2}$$

where i_t^m, i_t^x, i_t^n are investments[2] in all three sectors, k_t^m, k_t^x, k_t^n are capital stocks, w_t^m, w_t^x, w_t^n wage rates, and u_t^m, u_t^x, u_t^n rental rates of capital. The variable p_t^τ denotes the relative price of the tradable composite good in terms of final goods, d_t denotes the debt stock in period t (in units of the tradable composite good), and r_t denotes the interest rate on debt held from period t to $t+1$. Consumption, investment, wages, rental rates, debt, and capital adjustment costs are all expressed in units of final goods. The adjustment capital costs are presented by the functions $\Phi_j\left(k_{t+1}^j - k_t^j\right)$. By the quadratic form of the function, the adjustment cost parameters are denoted as

[2] The household budget contains the investment Since the households own the firms.

$\phi_m, \phi_x, \phi_n > 0$. The capital dynamics depends on investments and capital depreciation rate $0 < \delta < 1$.

$$k_{t+1}^m = (1-\delta)k_t^m + i_t^m, \tag{3}$$

$$k_{t+1}^x = (1-\delta)k_t^x + i_t^x, \tag{4}$$

$$k_{t+1}^n = (1-\delta)k_t^n + i_t^n. \tag{5}$$

The households maximise the utility function (1) subject to the constraints (2)-(5). According to the study's assumptions, the pandemic period is associated with shifts in labour supply and consumption demand expressed by the first-order conditions of the problem. Therefore, we present them.

$$\left[c_t - \frac{(h^m)^{\omega_m}}{\omega_m} + \frac{(h^x)^{\omega_x}}{\omega_x} + \frac{(h^n)^{\omega_n}}{\omega_n}\right]^{-\sigma} = \lambda_t, \tag{6}$$

$$\left(h_t^m\right)^{(\omega_m - 1)} = w_t^m \tag{7}$$

$$\left(h_t^x\right)^{(\omega_x - 1)} = w_t^x \tag{8}$$

$$\left(h_t^n\right)^{(\omega_n - 1)} = w_t^n \tag{9}$$

$$\lambda_t p_t^\tau = \beta\left(1 + r_t\right) E_t \lambda_{t+1} p_{t+1}^\tau \tag{10}$$

$$\lambda_t\left[1 + \phi_m\left(k_{t+1}^m - k_t^m\right)\right] = \beta E_t \lambda_{t+1}\left[u_{t+1}^m + 1 - \delta + \phi_m\left(k_{t+2}^m - k_{t+1}^m\right)\right] \tag{11}$$

$$\lambda_t\left[1 + \phi_x\left(k_{t+1}^x - k_t^x\right)\right] = \beta E_t \lambda_{t+1}\left[u_{t+1}^x + 1 - \delta + \phi_x\left(k_{t+2}^x - k_{t+1}^x\right)\right] \tag{12}$$

$$\lambda_t\left[1 + \phi_n\left(k_{t+1}^n - k_t^n\right)\right] = \beta E_t \lambda_{t+1}\left[u_{t+1}^n + 1 - \delta + \phi_n\left(k_{t+2}^n - k_{t+1}^n\right)\right] \tag{13}$$

In the Eqs. (6), and (10)-(13), λ_t denotes the Lagrange multiplier. The conditions (6–13) consider the mentioned functional forms. The first condition (6) specifies the consumption demand; the following three (7–9) specify the labour supply in all the sectors. The following (10) is the Euler equation for the debt, and the final three (11–13) are the Euler equations for the capital in all the sectors.

4.2 Firms

The inputs in final goods production are non-tradable goods a_t^n and a composite of tradable goods a_t^τ. The corresponding production function $B_t = B\left(a_t^\tau, a_t^n\right)$ is in the form of constant elasticity of input substitution.

$\mu_{\tau n} > 0$, and the tradeable input share $0 < \chi_\tau < 1$. The firms choose a_t^τ, a_t^n to maximise their profit.

$\mathrm{B}\left(a_t^n, a_t^\tau\right) - p_t^\tau a_t^\tau - p_t^n a_t^n$. The input prices are p_t^τ, p_t^n.

The production function of the firms producing the tradeable composite goods is also in the form of the constant elasticity of input substitution $\mu_{mx} > 0, a_t^\tau = \mathrm{A}\left(a_t^m, a_x\right)$. The inputs are importable and exportable goods a_t^m, a_t^x; the importable input share is $0 < \chi_m < 1$. Denoting the input prices as p_t^m, p_t^x, the firms maximise the profit $A\left(a_t^m, a_x\right) - p_t^m a_t^m - p_t^x a_t^x$.

The technology of the firms producing exportable, importable, and non-tradeable goods corresponds to the production function:

$$y_t^m = z_t^m F\left(k_t^m, h_t^m\right), \tag{14}$$

$$y_t^x = z_t^x F\left(k_t^x, h_t^x\right), \tag{15}$$

$$y_t^n = z_t^n F\left(k_t^n, h_t^n\right), \tag{16}$$

where z_t^m, z_t^x, z_t^n are total factor productivities in the sectors. The production functions (denoted by F) are in the Cobb–Douglas form with the capital shares (capital elasticity of output) $\alpha_m, \alpha_x, \alpha_n$. The capital shares are between 0 and 1, and the non-tradeable sector's capital share differs from the other two. The firms maximise the profit functions $p_j z_t^j F\left(k_t^j, h_t^j\right) - w_t^j h_t^j - w_t^j k_t^j$. Since the first-order conditions include the labour demand subject to shifts during the pandemic, we state them. We present them after considering the Cobb–Douglas production function form.

$$p_t^m \alpha_m z_t^m \left(k_t^m\right)^{\alpha_m - 1} \left(h_t^m\right)^{1-\alpha_m} = u_t^m, \tag{17}$$

$$p_t^m \left(1 - \alpha_m\right) z_t^m \left(k_t^m\right)^{\alpha_m} \left(h_t^m\right)^{-\alpha_m} = w_t^m, \tag{18}$$

$$p_t^x \alpha_x z_t^x \left(k_t^x\right)^{\alpha_x - 1} \left(h_t^x\right)^{1-\alpha_x} = u_t^x, \tag{19}$$

$$p_t^x \left(1 - \alpha_x\right) z_t^x \left(k_t^x\right)^{\alpha_x} \left(h_t^x\right)^{-\alpha_x} = w_t^x, \tag{20}$$

$$p_t^n \alpha_m z_t^n \left(k_t^n\right)^{\alpha_n - 1} \left(h_t^n\right)^{1-\alpha_n} = u_t^n, \tag{21}$$

$$p_t^n\left(1-\alpha_n\right)z_t^n\left(k_t^n\right)^{\alpha_n}\left(h_t^n\right)^{-\alpha_n}=w_t^n. \tag{22}$$

Since the production functions are homogenous with order 1, the firms' profits are always zero.

4.3 Market clearing

The general equilibrium requires that all markets clear. Namely, the final production supply equals the demand,

$$c_t+i_t^m+i_t^x+i_t^n+\phi_m\left(k_{t+1}^m-k_t^m\right)+\phi_x\left(k_{t+1}^x-k_t^x\right)+\Phi_n\left(k_{t+1}^n-k_t^n\right)=B_t. \tag{23}$$

Demand for non-tradeables equal the production of non-tradeables,

$$a_t^n=y_t^n. \tag{24}$$

Imports are defined as the difference between the domestic absorption of importables, a_t^m, and the importable output, y_t^m,

$$\mathrm{m_t}=\mathrm{p_t^m}\left(\mathrm{a_t^m}-\mathrm{y_t^m}\right), \tag{25}$$

where imports m_t are expressed in units of final goods, whereas importables a_t^m and importable output, y_t^m, are expressed in units of importable goods. Similarly, exports are defined as the difference between the exportable output and the domestic absorption of exportables,

$$x_t=p_t^x\left(y_t^x-a_t^x\right), \tag{26}$$

where exports x_t are expressed in units of final goods.

The economy-wide resource constraint is

$$\frac{p_t^\tau d_{t+1}}{1+r_t}=p_t^\tau d_t+m_t-x_t.$$

To ensure a stationary equilibrium process for external debt, we assume that the country's interest-rate premium is debt-elastic (Schmitt-Grohé and Uribe 2003)

$$r_t=r^*+\psi\left(e^{d_{t+1}-\bar{d}}-1\right), \tag{27}$$

where r^* denotes the sum of the world interest rate and the constant component of the interest-rate premium. The second term of (27) is the country's interest-rate premium's debt-elastic component. It equals 0 if the debt equals its steady-state value, $d_{t+1}=\bar{d}$. The parameter of debt service costs is $\psi>0$, and it plays an essential role in the study.

4.4 Observables

The study needs to compare the short-term model economy with the actual one. Therefore, it must derive the observable variables as real output and its components. Following the Uribe and Schmitt-Grohé (2017), observables are expressed using the Paasche GDP deflator. In the model, the real GDP is expressed as

$$y_t^0 = p^m y_t^m + p^x y_t^x + p^n y_t^n, \tag{28}$$

where ${y_t}^0$ is the real GDP, p^j, $j = m, n, x$, denotes the steady-state value of the relative price of good i in final consumption good units. Real consumption, investment, and trade balance at constant GDP prices denoted $c_t^0, i_t^0, x_t^0 - m_t^0$ is given by

$$c_t^0 = \frac{p^m y_t^m + p^x y_t^x + p^n y_t^n}{p_t^m y_t^m + p_t^x y_t^x + p_t^n y_t^n} c_t, \tag{29}$$

$$i_t^0 = \frac{p^m y_t^m + p^x y_t^x + p^n y_t^n}{p_t^m y_t^m + p_t^x y_t^x + p_t^n y_t^n} i_t, \tag{30}$$

$$x_t^0 - m_t^0 = \frac{p^m y_t^m + p^x y_t^x + p^n y_t^n}{p_t^m y_t^m + p_t^x y_t^x + p_t^n y_t^n} \left(x_t - m_t\right). \tag{31}$$

4.5 Model modifications

Let us modify the model to apply the changes induced by the shocks of the pandemic outbreak and the public policy responses. Assume that during the pandemic period, labour supply and demand shift. The shifts are caused by illness deaths of workers and by the distance restrictions. The restrictions force consumers to postpone consumption. Introduce the parameters shifting the functions. Rewrite the consumption demand into the form:

$$\left[\gamma_t c_t - \frac{(h^m)^{\omega_m}}{\omega_m} + \frac{(h^x)^{\omega_x}}{\omega_x} + \frac{(h^n)^{\omega_n}}{\omega_n}\right]^{-\sigma} = \lambda_t. \tag{32}$$

The γ parameter equals 1 in the steady state, shifting the demand for consumption. Substituting 1.01 for the parameter decreases the consumption demand by 1%.

The shifts in the labour supply are formed by rewriting (7–9):

$$\left(\nu_t h_t^m\right)^{(\omega_m - 1)} = w_t^m, \tag{33}$$

$$\left(\nu_t h_t^x\right)^{(\omega_x - 1)} = w_t^x, \tag{34}$$

$$\left(\nu_t h_t^n\right)^{(\omega_n - 1)} = w_t^n, \tag{35}$$

where the parameter shifting the labour supply is ν_t; in the steady state $\nu = 1$. Increasing the parameter by 1% decreases the labour supply by 1% in all three sectors.

The shifts in the labour demand are formed by rewriting (18, 20, and 22):

$$p_t^m \left(1 - \alpha_m\right) z_t^m \left(k_t^m\right)^{\alpha_m} \left(\zeta_t h_t^m\right)^{-\alpha_m} = w_t^m, \tag{36}$$

$$p_t^x \left(1 - \alpha_x\right) z_t^x \left(k_t^x\right)^{\alpha_x} \left(\zeta_t h_t^x\right)^{-\alpha_x} = w_t^x, \tag{37}$$

$$p_t^n \left(1 - \alpha_n\right) z_t^n \left(k_t^n\right)^{\alpha_n} \left(\zeta_t h_t^n\right)^{-\alpha_n} = w_t^n. \tag{38}$$

The parameter shifts the labour demand $\xi = 1$ in the steady state. A 1% increase in the parameter causes a 1% decrease in labour demand in all three sectors.

All shift parameters γ_t, ν_t, ζ_t together with the total factor productivity parameters z_t^m, z_t^x, z_t^n and the terms of trade defined as p_t^x / p_t^m are up to the AR (1) process in the form:

$$\ln\left(\frac{\nu_t}{\nu}\right) = \rho \ln\left(\frac{\nu_{t-1}}{\nu}\right) + \kappa_\nu \kappa_t, \tag{39}$$

$$\ln\left(\frac{\zeta_t}{\zeta}\right) = \rho \ln\left(\frac{\zeta_{t-1}}{\zeta}\right) + \kappa_\zeta \kappa_t, \tag{40}$$

$$\ln\left(\frac{\gamma_t}{\gamma}\right) = \rho \ln\left(\frac{\gamma_{t-1}}{\gamma}\right) + \kappa_\gamma \kappa_t, \tag{41}$$

$$\ln\left(\frac{p_t^x}{p_t^m}\frac{p^m}{p^x}\right) = \rho \ln\left(\frac{p_{t-1}^x}{p_{t-1}^m}\frac{p^m}{p^x}\right) + \kappa_p \kappa_t, \tag{42}$$

$$\ln\left(\frac{z_t}{z^m}\right) = \rho \ln\left(\frac{z_{t-1}^m}{z}\right) + \kappa_A \kappa_t, \tag{43}$$

$$\ln\left(\frac{z_t}{z^x}\right) = \rho \ln\left(\frac{z_{t-1}^x}{z}\right) + \kappa_A \kappa_t, \tag{44}$$

$$\ln\left(\frac{z_t}{z^n}\right) = \rho \ln\left(\frac{z_{t-1}^n}{z}\right) + \kappa_A \kappa_t. \tag{45}$$

The terms without a t index are the values in the steady state. The variables reacting to the pandemic shock denoted as κ_t, which is white noise with zero mean and standard

error s. The parameters $\kappa_\nu, \kappa_\zeta, \kappa_\gamma, \kappa_p$, and κ_A are the pandemic elasticities. The serial correlation coefficient is $\rho \in (-1,1)$.

Besides, we add the following observables: the labour N

$$N_t = h_t^m + h_t^x + h_t^n,$$

and the average product of labour y_t^0/N_t.

5 Methods

To verify the effect of pandemic shock κ, we need to compute the competitive equilibrium by solving all the equations, including all first-order conditions of the firms and consumers. The model consists of a system with many nonlinear equations. It is approximated to the linear state space form to solve it. Therefore, we need to evaluate the parameters and approximate the model equations.

5.1 Calibration

By model calibration, we must choose the coefficient values so that the primary model economy characteristics in the steady-state correspond to the observed characteristics of the countries studied. Log-linearisation is applied to transform the model into a linear form.

From the set of parameters $\{\beta, \sigma, \omega_m, \omega_x, \omega_n, \phi_m, \phi_x, \phi_n, \delta, \mu_{\tau n}, \mu_{mx}, \chi_\tau, \chi_m, \alpha_m, \alpha_x, \alpha_n, z^m, z^x, z^n, r^*, \overline{d}, \nu, \zeta, \gamma, \kappa_\nu, \kappa_\gamma, \kappa_p, \kappa_A, \rho, s\}$, a subset is calibrated using existing RBC literature. Another subset is calibrated based on the production and international trade characteristics of the studied economies gained from the various world databases. A subset of parameters is computed using the parameters from the first two subsets so that the economy corresponds to the steady state. The rest of the parameters play a role in equilibrium dynamics. Our task is to set their values so that the model moments of observables match those of the published data series during pandemics.

We adopt a value of inverse Frisch elasticity $\omega_i - 1$ from Uribe and Schmitt-Grohé (2017), particularly, $\omega_i = 1.455, \forall i \in \{m, x, n\}$. Following the example of the literature using GHH preferences, we set the intertemporal elasticity of consumption substitution $\sigma = 2$ (Mendoza 1991). The elasticity of substitution between importables and exportables $\mu_{mx} = 0.85$. Akinci (2011) states that the studies for estimating the elasticity of substitution between tradeable and non-tradeable goods using the cross-section data estimate the parameter in the interval (0.43, 0.74). We set $\mu_{\tau n} = 0.5$.

The Penn World Tables (PWT) (Feenstra et al. 2015) help find the economies' production characteristics. We set the capital depreciation rate $\delta = 0.01$ for big and small countries. This value corresponds to the value gathered from the PWT considering that our quarterly data is used to compute the cyclical characteristics. Using the PWT, we estimate the labour share to be 0.55 in the small countries and 0.58 in the big ones. We calculated the average shares by averaging for

small and large countries in the last 5 and 10 years before the pandemic outbreak. We selected suitable values according to the dynamics of the shares. The non-tradeable sector's labour share must not be equal to that of the other two sectors. Considering that the labour share estimate based on the compensations of employees (as estimated in the PWT) is underestimated (Gollin 2002) and assuming that the non-tradeable is work-intensive, we set $\alpha_m = \alpha_x = 0.45, \alpha_n = 0.35$ in the small countries, and $\alpha_m = \alpha_x = 0.42, \alpha_n = 0.32$ in the big countries. Considering the quarterly data frequency and the PWT data, the world interest rate equals $r^* = 0.02$.

The steady state implies the following values of the parameters: $z^m = z^n = p^x/p^m = \nu = \gamma = \zeta = 1, \beta(1 + r^*) = 1$.

The procedure of Uribe and Schmitt-Grohé (2017) is used, to calibrate the parameters characterising the international trade. We need the following characteristics:

- The average value-added export share s_x
- The average share of exportable output in GDP s_{yx}
- The average share of non-tradable output in GDP s_{yn}
- The average value-added trade balance share GDP s_{tb}

We used data from the UNCTADstat (2023) database. We obtained annual panel data on sectors' value-added shares in the 27 countries studied. The database distinguishes three main sectors: "Agriculture, hunting, forestry, fishing", "Industry", and "Services". We consider the last of the sectors non-tradable. The shares in services thus represent the average share of non-tradable output in GDP s_{yn}.

The Merchandise trade matrix database from the UNCTADstat (2023) database (Data/Trade in Merchandise) provides annual panel data on the exports and imports of the surveyed countries in various manufacturing sectors. Since the sectoral breakdown is more detailed in the database, following the example of Uribe and Schmitt-Grohé (2017), we included the subsectors All food items (SITC $0+1+22+4$) and Agricultural raw materials (SITC 2 less 22, 27 and 28) to the agricultural sector. In industry, we classify Fuels (SITC 3), Manufactured goods (SITC 5 to 8 less 667 and 68), Memo: Ores, metals precious stones and non-monetary gold (SITC $27+28+68+667+971$).

The last database is the annual panel data on the export and import of services in the studied countries.

In all three main sectors of each country and each year, we calculated the product of the sector's value-added share with the $exports/(exports + imports)$ ratio. By adding up these shares in agriculture and industry in each country and each year, we obtained the value-added export share s_x.

If we sum these shares each year and country in all sectors, including services, we get the share exports in tradable products. Let us denote it by $s_{x\tau}$. The share of exportable output in GDP is calculated as the product of the share of exportable output in tradable with the share of tradable output in all products, $s_{yx} = s_{x\tau}(1 - s_{yn})$.

We obtained data on the share of the trade balance in GDP from the database The External Wealth of Nations (Lane and Milesi-Ferretti 2018 and Milesi-Ferretti 2022). We calculate the indicator as

$$s_{tb} = \frac{r}{1+r} b,$$

where r is the country's interest rate, and b is the share of the net international investment position in GDP.

We use those calculations to compute the following parameters. The share of importables is computed as

$$\chi_m = \frac{\left[\Upsilon (p^x/p^m)^{(\mu_{mx}-1)}\right]^{(-1/\mu_{mx})}}{1+\left[\Upsilon (p^x/p^m)^{(\mu_{mx}-1)}\right]^{(-1/\mu_{mx})}}, \tag{46}$$

where

$$\Upsilon = \frac{p^x a^x}{p^m a^m} = \frac{s_{yx} - s_x}{1 - s_{yx} - s_{yn} + s_x - s_{tb}} \tag{47}$$

Table 2 Model calibration

	Small	Big		Small	Big		Small	Big
δ	0.01	0.01	s_x	0.1400	0.1300	χ_m	0.9705	0.9500
α_x	0.48	0.45	s_{yx}	0.1540	0.1512	χ_τ	0.9583	0.9400
α_m	0.48	0.45	s_{yn}	0.7200	0.7200	β	0.9804	0.9800
α_n	0.38	0.35	s_{tb}	-0.0070	-0.0050	z^x	1.0350	1.0300
r^*	0.02	0.02				$\bar{d}$	-3.1627	-1.1859
μ_{mx}	0.85	0.85				ϕ_m	*	*
$\mu_{\tau x}$	0.5	0.5				ϕ_x	*	*
σ	2	2				ϕ_n	*	*
ω_x	1.455	1.455				ψ	*	*
ω_m	1.455	1.455				ρ	*	*
ω_n	1.455	1.455				s	*	*
z^m	1	1				κ_ν	*	*
z^x	1	1				κ_ζ	*	*
p^x/p^m	1	1				κ_γ	*	*
ν	1	1				κ_p	*	*
γ	1	1				κ_a	*	*
ζ	1	1						

Uribe and Schmitt-Grohé (2017), Feenstra et al. (2015), Akinci (2011), Mendoza (1991), European Commission (2017), Lane and Milesi-Ferretti (2018), UNCTADstat (2023) https://unctadstat.unctad.org/datacentre/, and own processing

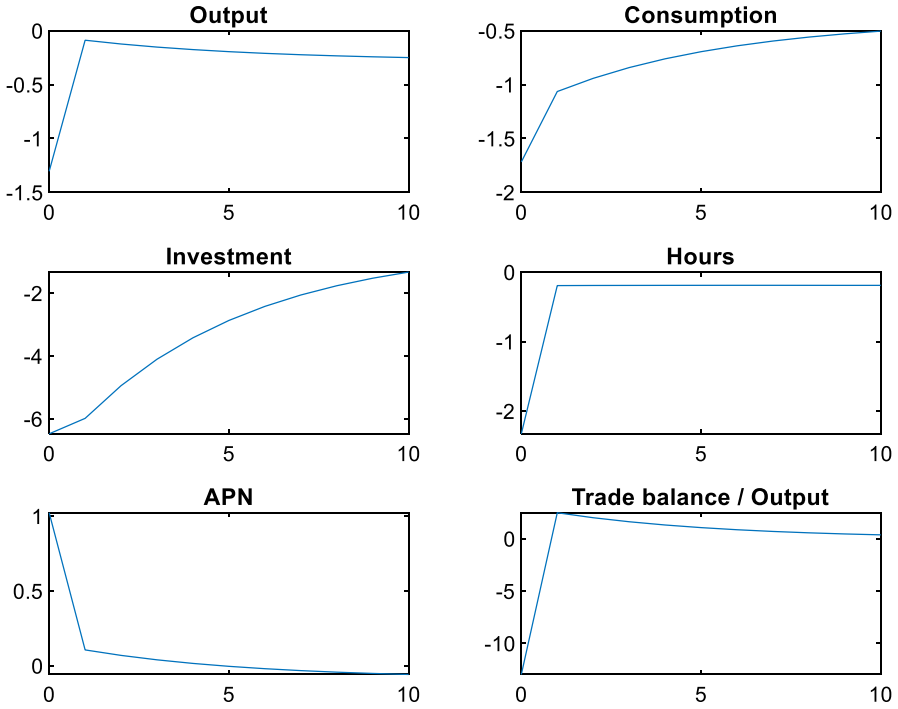

Fig. 1 Model Calibration: pandemic shock impulse response functions in small countries. *Source* own processing

Table 3 Calibration of the Reactions to Pandemic Shock

	ϕ	ψ	ρ	s	κ_ν	κ_ζ	κ_γ	κ_p	κ_a
Small	1.81	0.005	0	0.0277	1	0	0	−1.9	0
Big	0.4	0.001	0	0.1041	1	0	0	−0.65	0

Own processing

is the steady-state exportable-to-importable absorption ratio. Having Υ and χ_m, we can compute the a^x/a^m and a^τ/a^n ratios implying χ_τ. All parameters needed to compute the steady state are disposable.

Table 2 summarises the calibrated coefficients (the left panel), data restrictions (the middle panel), and the implied coefficients (the right panel). The coefficients denoted with asterisks are calibrated so the model replicates observed cyclical characteristics. Their obtaining is to be explained at the end of the chapter.

5.2 Log-linearisation and linear state space

The model consisting of nonlinear equations can be written in the form

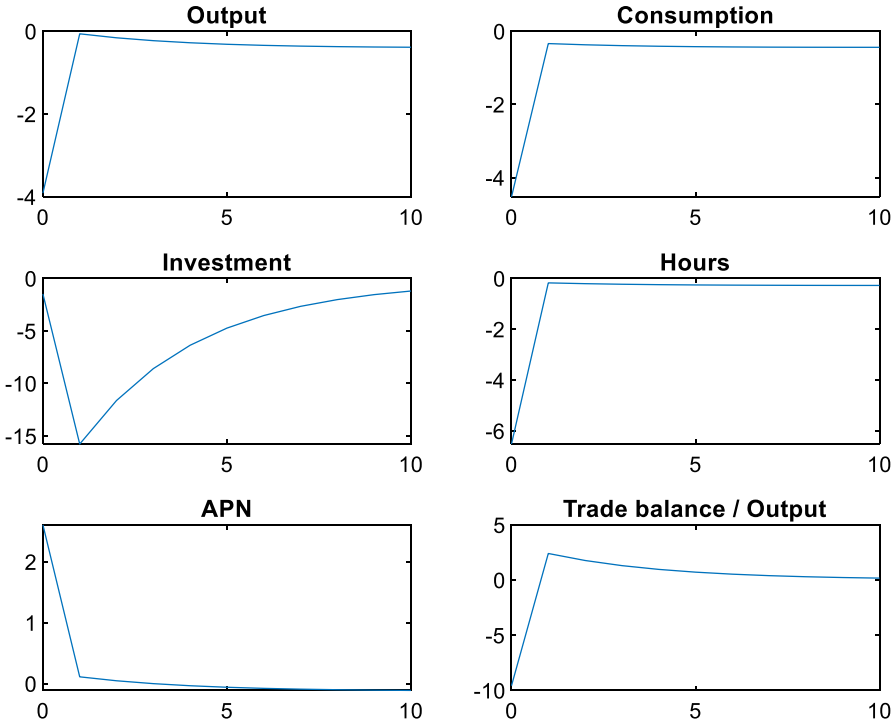

Fig. 2 Model Calibration: pandemic shock impulse response functions in big countries. *Source* own processing

Table 4 Model and observed cyclical characteristics of EU27 Countries

		GDP	Cons	Inv	Lab	Aver.prod.of lab	Net exp
Small countries in the pandemic period	Std. Devs	4.25%	5.06%	13.42%	6.15%	4.48%	4.27%
	Cor. w. GDP	1.00	0.74	0.27	0.69	0.01	0.25
	Ser. Cor	−0.09	−0.35	−0.13	−0.28	0.01	−0.07
Model small countries	Std. Devs	4.25%	5.06%	13.42%	3.65%	1.62%	13.64%
	Cor. w. GDP	1.00	0.93	0.55	0.93	0.53	0.25
	Ser. Cor	0.91	0.93	0.87	0.63	0.64	-0.10
Big countries in the pandemic period	Std. Devs	5.44%	5.63%	8.44%	7.94%	3.42%	1.19%
	Cor. w. GDP	1.00	0.93	0.65	0.94	−0.59	0.64
	Ser.Cor	−0.24	−0.42	0.18	−0.09	0.02	0.34
Model big countries	Std. Devs	5.44%	5.63%	13.58%	7.01%	2.83%	10.29%
	Cor. w. GDP	1.00	0.99	0.59	0.93	-0.38	0.64
	Ser. Cor	0.49	0.64	0.90	0.16	0.18	-0.05

Own processing

$$f\left(y_t, y_{t+1}, x_t, x_{t+1}\right) = 0 \tag{48}$$

Table 5 Calculations for small and big countries during the pandemic using various methods

	Small countries in the pandemic period						Big countries in the pandemic period					
Christiano-Fitzgerald	y	c	i	N	apn	x	y	c	i	N	apn	x
Std. Devs	0.030	0.031	0.092	0.030	0.024	0.131	0.030	0.027	0.056	0.039	0.015	0.017
Std. Devs to GDP	1.000	1.021	3.063	0.984	0.780	4.347	1.000	0.896	1.894	1.309	0.514	0.569
Corr. with GDP	1.000	0.767	0.312	0.652	0.395	0.200	1.000	0.903	0.756	0.935	–0.435	0.417
Ser. Cor	0.666	0.615	0.824	0.736	0.829	0.967	0.586	0.533	0.683	0.743	0.958	0.879
Hamilton(5,4)	y	c	i	N	apn	x	y	c	i	N	apn	x
Std. Devs	0.056	0.062	0.185	0.065	0.052	0.083	0.059	0.059	0.110	0.079	0.040	0.014
Std. Devs to GDP	1.000	1.093	3.282	1.145	0.930	1.469	1.000	1.000	1.858	1.340	0.678	0.240
Corr. with GDP	1.000	0.653	0.234	0.570	0.138	0.319	1.000	0.921	0.734	0.885	–0.545	0.622
Ser. Cor	0.246	–0.015	0.280	–0.170	0.252	0.436	–0.136	–0.374	0.385	–0.112	0.172	0.475
Hamilton(5,–)	y	c	i	N	apn	x	y	c	i	N	apn	x
Std. Devs	0.059	0.065	0.278	0.074	0.065	0.152	0.069	0.070	0.109	0.096	0.041	0.014
Std. Devs to GDP	1.000	1.107	4.745	1.261	1.104	2.598	1.000	1.004	1.565	1.376	0.585	0.197
Corr. with GDP	1.000	0.524	–0.126	0.544	0.285	0.463	1.000	0.932	0.739	0.927	–0.470	0.689
Ser. Cor	0.296	0.003	0.240	–0.163	0.374	0.341	0.091	–0.151	0.288	0.042	0.117	0.409
Hamilton(8,4)	y	c	i	N	apn	x	y	c	i	N	apn	x
Std. Devs	0.053	0.058	0.155	0.062	0.046	0.057	0.054	0.057	0.098	0.078	0.036	0.016
Std. Devs to GDP	1.000	1.094	2.936	1.179	0.873	1.073	1.000	1.053	1.815	1.436	0.673	0.300
Corr. with GDP	1.000	0.593	0.278	0.492	0.119	0.348	1.000	0.927	0.687	0.883	–0.560	0.361
Ser. Cor	0.253	–0.069	0.280	–0.236	0.097	0.293	–0.244	–0.384	0.437	–0.116	0.096	0.638
Hamilton(8,–)	y	c	i	N	apn	x	y	c	i	N	apn	x
Std. Devs	0.058	0.064	0.182	0.069	0.071	0.091	0.066	0.068	0.090	0.086	0.044	0.016
Std. Devs to GDP	1.000	1.098	3.144	1.188	1.230	1.570	1.000	1.028	1.361	1.306	0.670	0.247
Corr. with GDP	1.000	0.351	–0.059	0.378	0.448	0.507	1.000	0.928	0.645	0.864	–0.193	0.620

Table 5 (continued)

	Small countries in the pandemic period						Big countries in the pandemic period					
Christiano-Fitzgerald	y	c	i	N	apn	x	y	c	i	N	apn	x
Ser. Cor	0.384	0.122	0.168	–0.174	0.441	0.318	0.174	0.027	0.201	0.022	0.288	0.599
Hodrick-Prescott	y	c	i	N	apn	x	y	c	i	N	apn	x
Std. Devs	0.043	0.051	0.134	0.062	0.045	0.043	0.054	0.056	0.084	0.079	0.034	0.012
Std. Devs to GDP	1.000	1.189	3.157	1.446	1.053	1.005	1.000	1.037	1.553	1.461	0.629	0.219
Corr. with GDP	1.000	0.739	0.268	0.685	0.010	0.252	1.000	0.934	0.648	0.937	–0.586	0.639
Ser. Cor	–0.090	–0.354	–0.131	–0.277	0.010	–0.075	–0.238	–0.425	0.185	–0.094	0.015	0.339

Own processing

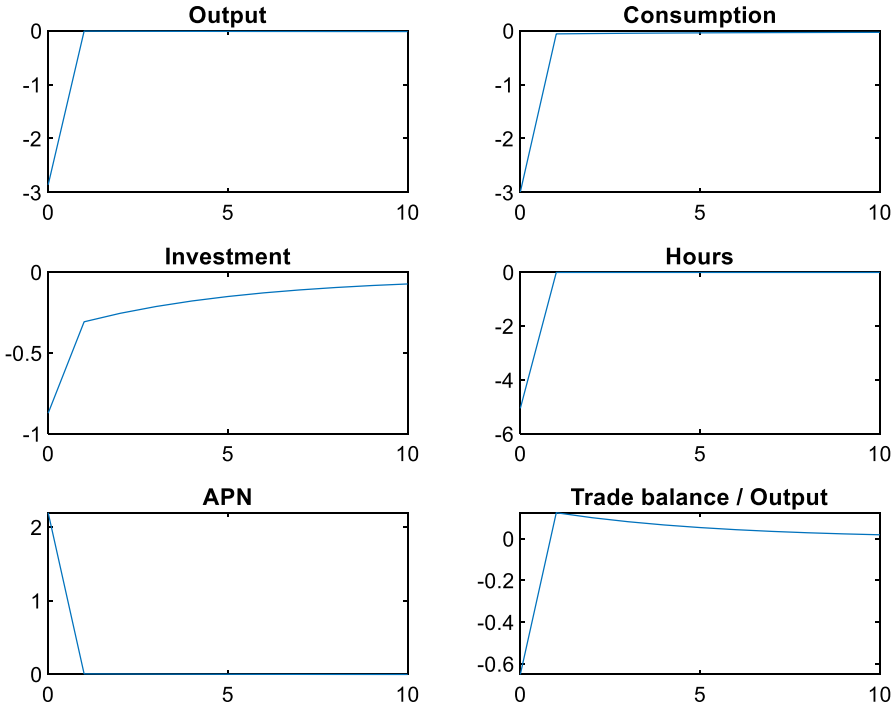

Fig. 3 The impulse response of a 10% decrease in labour supply in small countries. *Source* own processing

where the vector of control variables is denoted as y, and state variables as x, a nonlinear vector function is f. The state variables in our model are $k_t^m, k_t^x, k_t^n, \nu_t, z_t^m, z_t^x, z_t^n, p_t^x/p_t^m, \gamma_t, \zeta_t, d_t, \kappa_t$. The rest are control variables.

The steady-state $[y, x]$ solves

$$f(\boldsymbol{y}, \boldsymbol{y}, \boldsymbol{x}, \boldsymbol{x}) = 0 \tag{49}$$

Using the computations of Uribe and Schmitt-Grohé (2017) and applying the log-linear approximation based on the first-order Taylor expansion around the steady-state point, we gain

$$\mathbf{F}_{\mathbf{y}'}\widehat{\mathbf{y}}_{\mathbf{t}+1} + \mathbf{F}_{\mathbf{y}}\widehat{\mathbf{y}}_{\mathbf{t}} + \mathbf{F}_{\mathbf{x}'}\widehat{\mathbf{x}}_{\mathbf{t}+1} + \mathbf{F}_{\mathbf{x}}\widehat{\mathbf{x}}_{\mathbf{t}} = 0 \tag{50}$$

where $\widehat{y}_t, \widehat{x}_t$ denote deviations from the steady state, and $F_{y\prime}, F_y, F_{x\prime}, F_x$ are the gained matrices.

We adopt the computations of Klein (2000), Sims (2002) and Uribe and Schmitt-Grohé (2017) to apply generalised Schur matrix decomposition, obtaining the linear state space form of the model.

$$\widehat{\mathbf{x}}_{\mathbf{t}+1} = \mathbf{H}_{\mathbf{x}}\widehat{\mathbf{x}}_{\mathbf{t}} + \mathbf{C}\boldsymbol{\kappa}_{\mathbf{t}+1} \tag{51}$$

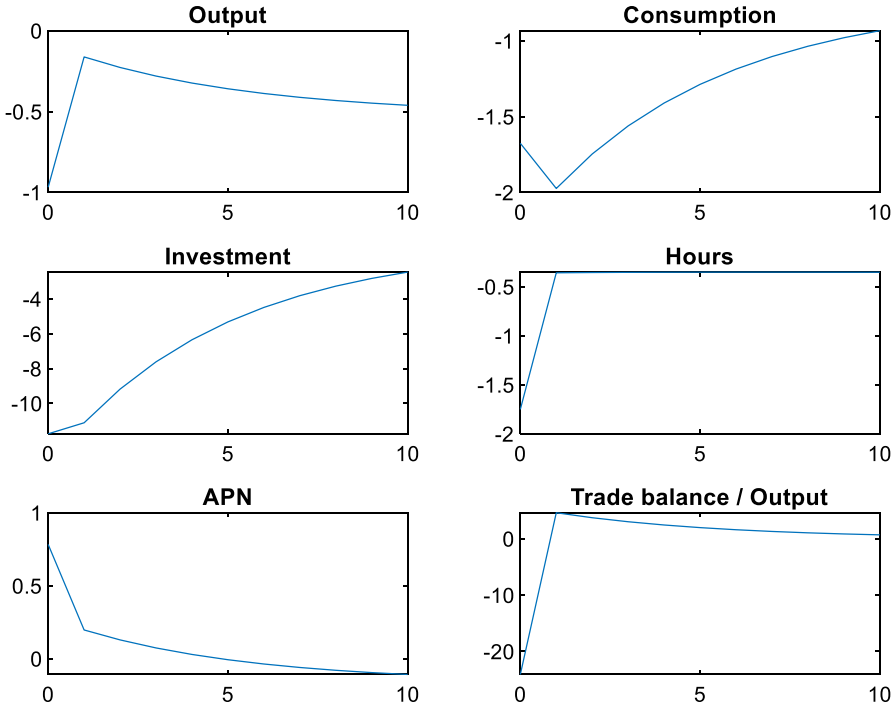

Fig. 4 The impulse response of a 10% decrease in terms of trade in small countries. *Source* own processing

$$\hat{\mathbf{y}}_\mathbf{t} = \mathbf{G}_\mathbf{x}\hat{\mathbf{x}}_\mathbf{t} \tag{52}$$

where $\mathbf{H}_\mathbf{x}$ is the transition matrix, $\mathbf{C}$ is the volatility matrix, and $\mathbf{G}_\mathbf{x}$ is the output matrix. The state space form allows us to apply the Lyapunov equation to compute stationary distributions of both control and state variables. Uribe and Schmitt-Grohé (2017) provide the needed computations. In this way, we can compute the covariance-variance matrix of the state and control variables conditional on pandemic shock with standard error s, the autocorrelation ρ, pandemic elasticities κ_ν, κ_ζ, κ_γ, κ_p, and κ_A. The observables' theoretical cyclical characteristics (moments) are computed from the variance–covariance matrices. We need to set the values so that the theoretical moments fit the observed characteristics. We change the values in iterations. We start with the small countries, followed by the big ones.

5.3 Pandemic calibration

Replicating the observed cyclical characteristics with the MXN model takes work. The graphs of impulse-response functions help identify the main manifestations of pandemic shock (see Figures 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 in Appendix). After

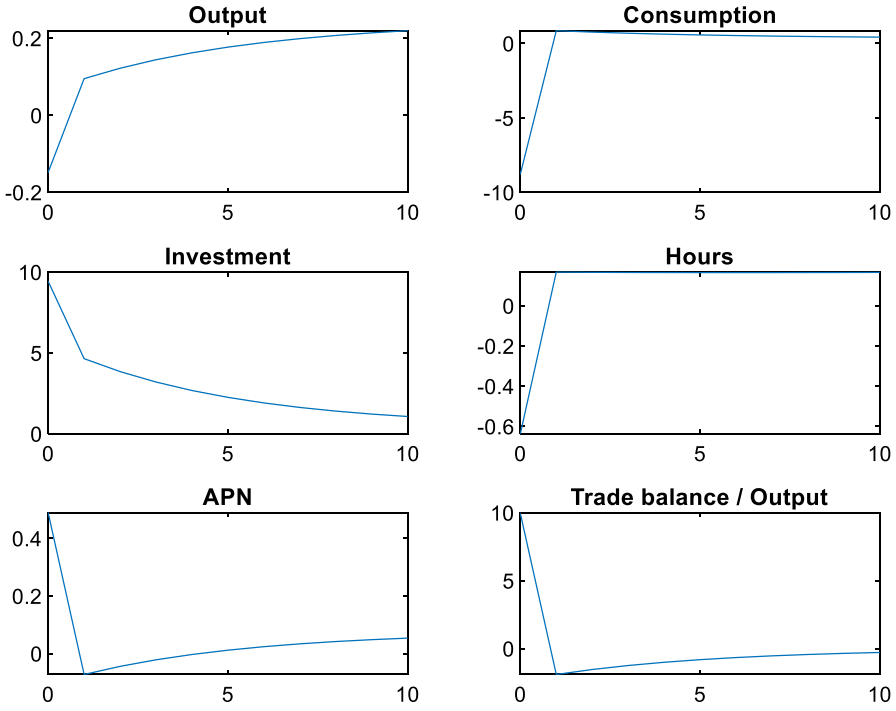

Fig. 5 The impulse response of a 10% decrease in consumption demand in small countries. *Source* own processing

more extended experimentation, we concluded that the pandemic shock was mainly associated with shifts in labour supply $\kappa\nu$, terms of trade κ_p and an increase in parameters characteristic of financial market imperfections, capital adjustment costs ϕ_x, ϕ_m, ϕ_n and the price of debt service ψ.

According to Cardani et al. (2022), Eichenbaum et al. (2022b), Lepetit and Fuentes-Albero (2022), Crucini and O'Flaherty (2020), Eichenbaum et al. (2021), the decline in consumption demand was supposed to explain the unusual volatility of consumption and investment in large countries. Demand for consumption may have been temporarily reduced by the postponement of consumption forced by the lockdown. However, according to the impulse-response function of the shift in consumption demand (Figures 5, 10), the trade balance will increase after the reduction in consumption demand, contrary to observations. Investments will not decrease immediately but will fall sharply later. Therefore, the change in the parameter $\kappa\gamma$ does not contribute to the explanation of the low volatility of investments. It turned out that by changing the values of capital adjustment costs ϕ_x, ϕ_m, ϕ_n, the share of volatilities between consumption and output can be better replicated.

Shifting the total factor productivity helps to set the investment volatility in big countries, but at the expense of the volatility of international trade. Moreover, the labour and the average product of labour changed in the opposite direction as output

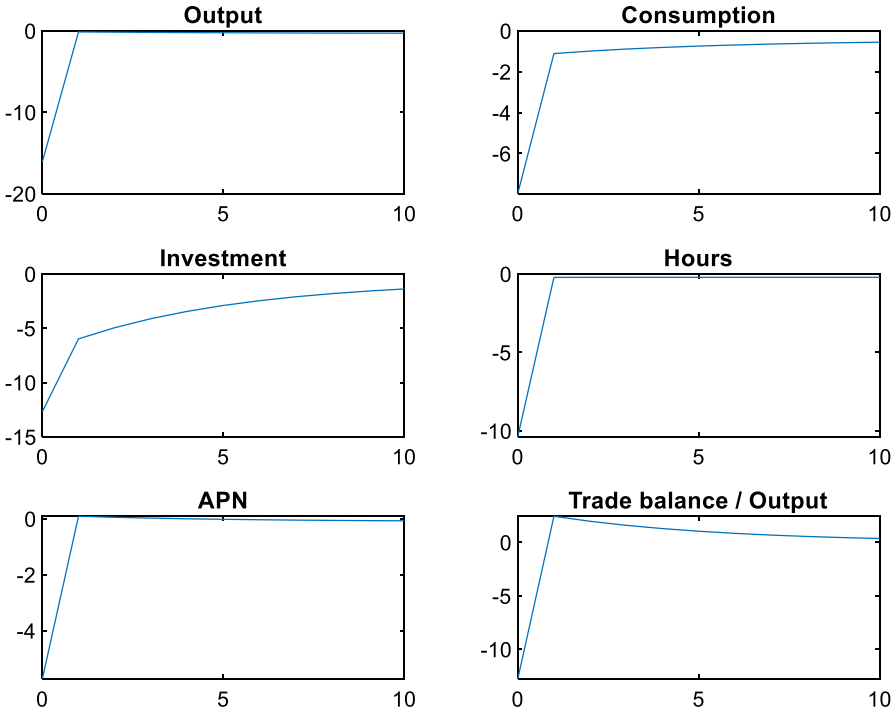

Fig. 6 The impulse response of a 10% decrease in total factor productivity in small countries. *Source* own processing

as a reaction to the total factor productivity shock (Figures 6, 11). Therefore, we set $\kappa_A = 0$.

After several attempts to adapt the input values so that the model reliably explains the macroeconomic performance of the EU countries during the pandemic, we needed to prioritize some of the output values. We focused on the output and consumption volatility and the correlation between trade balance and output. In the case of small countries, we found the correct investment volatility using changes in ψ. We chose the following iterative procedure.

- With a positive standard deviation s, we determine the labour supply elasticity $\kappa_\nu = 1$.
- Set the elasticity of terms of trade κ_p so that the value of the correlation between GDP and trade balance fits.
- Set standard error so that the output volatility fits.
- Set the capital adjustment cost parameters $\phi = \phi_x = \phi_m = \phi_n$ to fit the volatility ratio between output and consumption.
- Set the debt service parameter ψ so that the investment volatility fits.

Steps 2–5 are done simultaneously so that all set values match the target ones. We choose the HP filter computation of the moments as the target values (see Data

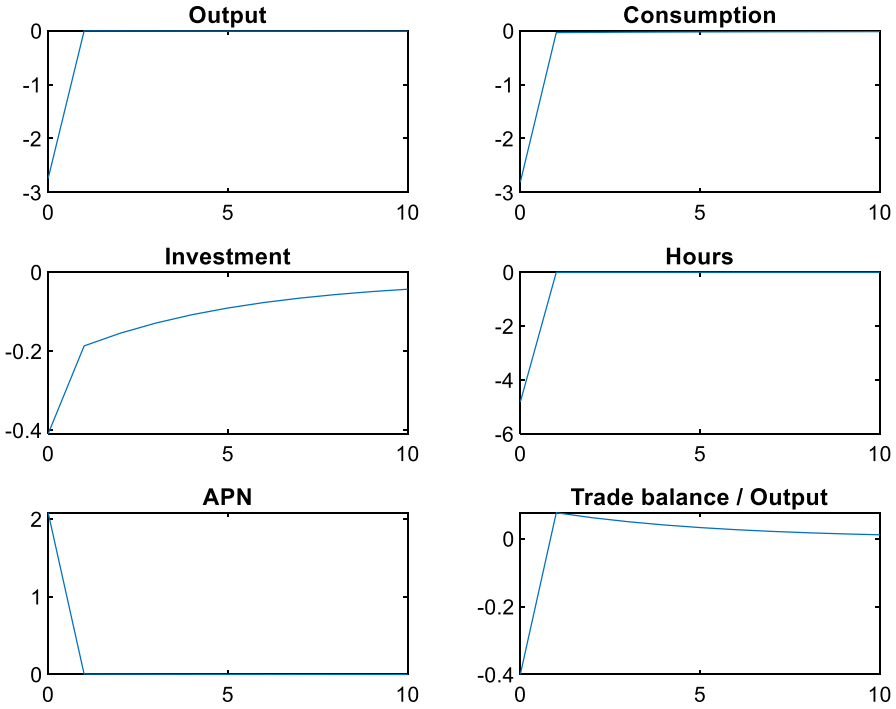

Fig. 7 The impulse response of a 10% decrease in labour demand in small countries. *Source* own processing

chapter). Table 3 shows the final parameter values for the small and big countries. Since all previous steps are repeated after each step, changing the order of individual steps does not affect the result. Impulses on pandemic shock in small and big countries are in Figs. 1 and 2.

The corresponding theoretical moments are in Table 4. Unlike in big countries, we successfully replicated the investment volatility in small countries using the debt service costs ψ. Impulses on pandemic shock in small and big countries are in Figs. 1 and 2.

6 Discussion

According to the observed cyclical characteristics during the pandemic, small open economies in the EU differ from large ones and the characteristics stated in other studies. The overall volatility of economic activity is relatively small; the volatility of investments and consumption does not significantly differ from cyclical characteristics in other periods.

By examining the model responses in the pandemic period, we find that European small open economies were subject to different shocks compared to large countries but also compared to the considerations of the existing literature dealing with the

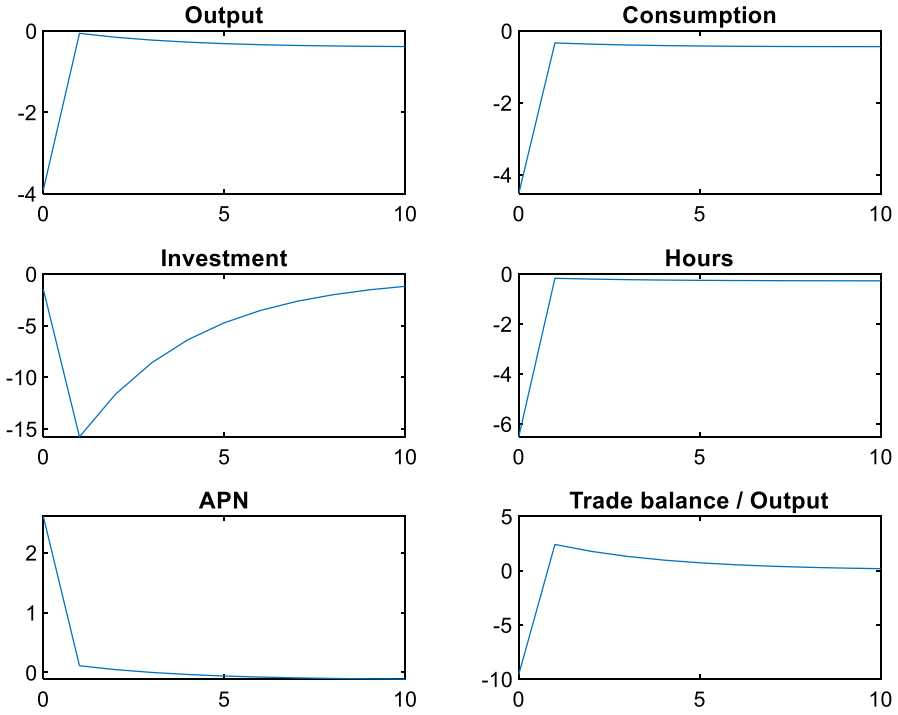

Fig. 8 The impulse response of a 10% decrease in labour supply in big countries. *Source* own processing

responses of economies in the pandemic, whose research did not use small open economies' data.

The MXN model (Uribe and Schmitt-Grohé, 2017) reliably explained the volatility of output, consumption, investment and the relationship between net exports and output. The model volatility of labour and the average product of labour is smaller than the actual values, and the model volatility of net exports is higher. The correlation coefficients between the variables and the output match the observations at least qualitatively: the investment-output correlation coefficient is smaller than the consumption-output and the labour-output correlation coefficients. According to observations, the average product of labour was not correlated with GDP. Its low value using European data is surprising. Usually, the average product of labour is procyclical. In the full sample, the study computes the correlation coefficient between output and the average product of labour to be only 0.21.

The observed cyclical characteristics in large countries coincide with the results of other studies in the literature. The peculiarity of the pandemic period is the relatively high volatility of consumption and low volatility of investments, which is more persistent than consumption and output. The model reliably explained volatilities, output, consumption and the relationship between net exports and output. The model values of labour and the average product of labour volatilities are close to the observed values. Even though the correlation coefficients of the variables with the output were not among the priorities, their theoretical values are, with exceptions,

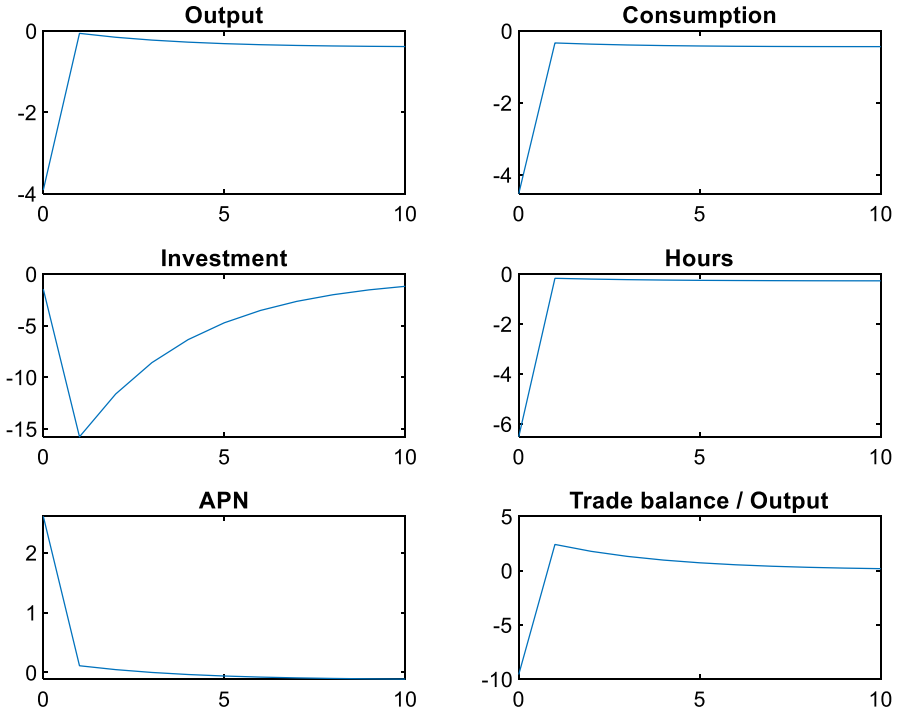

Fig. 9 The impulse response of a 10% decrease in terms of trade in big countries

close to the observed ones. Let us repeat the suspicion that the data underestimate the correlation coefficient between the average product of labour and output. The serial correlation values do not match, but the model at least assumes a higher persistence of investments; consumption persistence is higher than GDP.

The shock's autocorrelation coefficient is used to determine the individual autocorrelation coefficients of variables and the volatilities of consumption output and investment. Let us recall that the more persistent shock assumes greater consumption volatility and lower investment volatility. After unsuccessfully experimenting with ρ, we concluded that the pandemic period was not characterised by a regular recurrence of equally intense and persistent shocks. Pandemic waves and political responses varied in intensity across states and over time. Therefore, we set $\rho = 0$. Cardani et al. 2022; Eichenbaum et al. 2022b; Lepetit and Fuentes-Albero 2022; Crucini and O'Flaherty 2020; Eichenbaum et al. 2021 addressed unusual volatility in consumption, investment, and a decline in consumer demand (deferred consumption). By experimenting with the MXN model, the change in consumer demand κ_γ did not produce the desired result. Analogously, changes in total factor productivity did not help. We solved the volatility of consumption by changing adjustment capital costs ϕ. For small countries, we successfully replicated the volatility of investments using debt services costs. Those results indicate that pandemic shock is associated

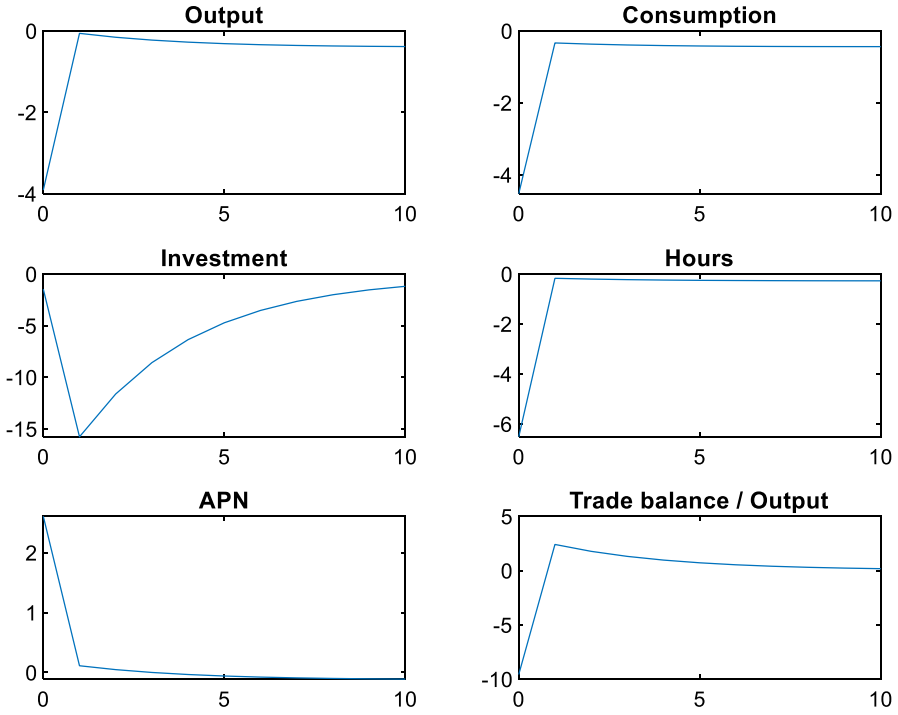

Fig. 10 The impulse response of a 10% decrease in consumption demand in big countries. *Source* own processing

with higher financial costs due to market frictions. Using an international sample of publicly listed firms, Vo et al. (2022) found that, on average, firms tend to adjust their capital structure more rapidly in the period following the breakout of COVID-19. Financial frictions are essential to the new Keynesian DSGE model, which Acurio Vásconez et al. (2023) used to evaluate unconventional monetary policy.

Changes in the labour supply caused the main macroeconomic changes in the pandemic period in large countries. This result corresponds to research worldwide. The model volatility of labour supply is around 10%. However, trade shocks also played a significant role. The increase in capital adjustment costs explains the high consumption volatility.

In small countries, the research results in surprisingly low volatility in labour supply (approximately 3%). The rest of the fluctuations are attributed to trade shocks and uncertainty in financial markets. The high cost of debt service explains the low volatility of investments. The consequence of increasing ψ was the necessity to increase capital adjustment costs in order to replicate the values of consumption and output volatilities.

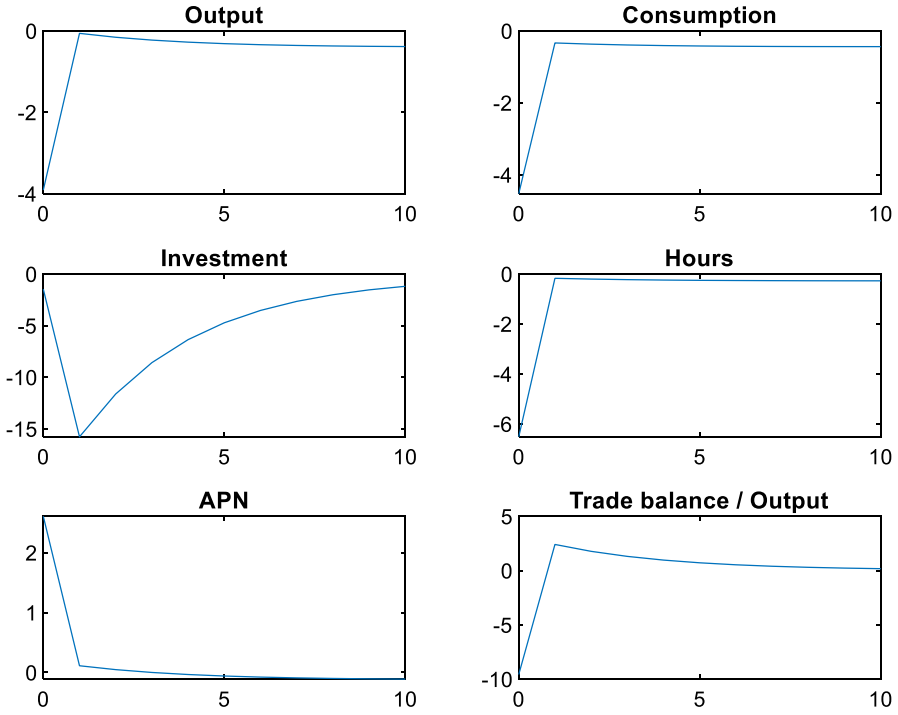

Fig. 11 The impulse response of a 10% decrease in total factor productivity in big countries. *Source* own processing

7 Conclusion

The study deals with macroeconomic responses in small open countries of the European Union during the COVID-19 pandemic. Quarterly panel data on GDP, investments, consumption, net exports, labour, and the average product of labour in the EU27 countries were used to express the cyclical characteristics. The cyclic components of the series were calculated using the Hodrick and Prescott filters (1997). Due to the robustness, other methods were used to compute the cyclical components in the small and big EU countries during the pandemic. Different filters vary by different calculated economic volatility. In big countries, consumption was unusually more volatile than GDP; conversely, investment was unusually low-volatility compared to output. These specifics have not been shown in small countries. The low correlation of output with labour and the average product of labour indicated that the pandemic was less associated with fluctuations in labour demand and supply in small countries. According to the results, during the pandemic period, the cyclical characteristics of small countries differed significantly from those of large countries, as did the results of other studies worldwide. The cyclical characteristics of the pandemic period were not significantly different for small countries compared to other periods. Therefore, there was an indication that the primary source of

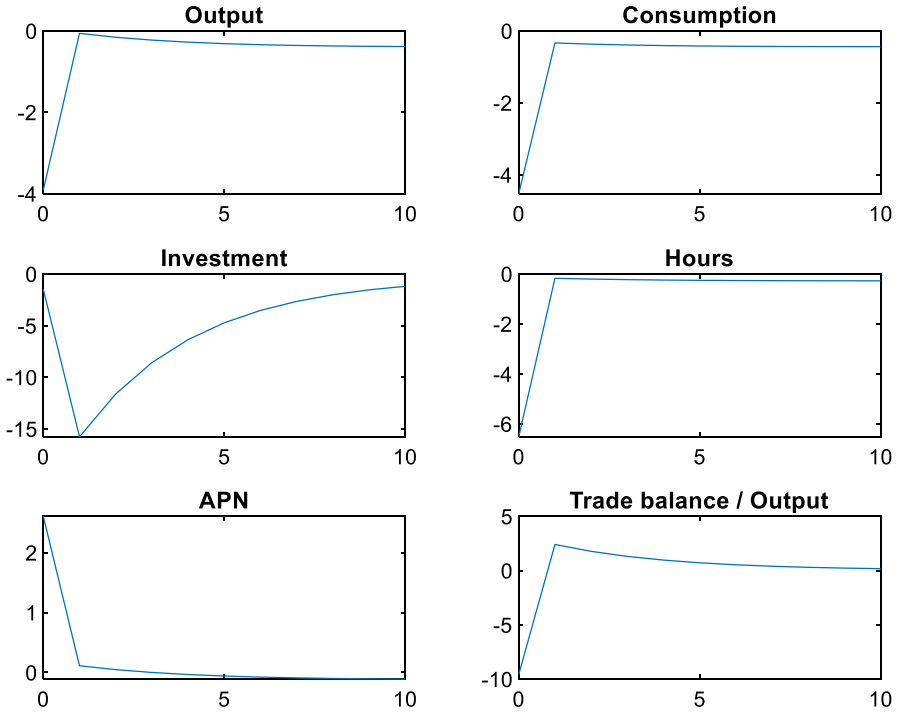

Fig. 12 The impulse response of a 10% decrease in labour demand in big countries. *Source* own processing

macroeconomic changes in small countries is trade shocks and changes in financial markets.

The cyclical characteristics of large countries during the pandemic period were consistent with current research. Economic volatility was higher than in other periods; investments had unusually low volatility, while consumption was unusually highly volatile.

The paper used the MXN model from Uribe and Schmitt-Grohé (2017) to explain the observed cyclical characteristics in the EU27 countries. In addition to regular shocks, trade shocks can be formulated in the model, the impact of which is refined due to the existence of a sector producing non-tradable products. The modification of the model consisted of the formulation of the pandemic shock, which affected the supply and demand of labour, consumer demand, total factor productivity, and terms of trade. Calculating variance–covariance matrices of state and control variables conditional on the pandemic shock made it possible to calculate the theoretical cyclical characteristics of the investigated variables. The iterative method was used to determine the values of the calibrated parameters so that the theoretical cyclic characteristics were closer to the observed ones.

In small countries, economic activity changed mainly due to changes in terms of trade, followed by labour supply. Volatility ratios of consumption output and investment correspond to higher capital adjustment and debt service costs. In large

countries, the primary macroeconomic source of change was labour supply, followed by trade shocks. The capital adjustment shock explained the low volatility of consumption above.

The study's results do not attribute the unusual volatility of consumption to changes in consumer demand but to an increase in capital adjustment costs. In small countries, the volatility of investments can be explained by an increase in debt service costs.

This work argues that small European countries responded to the outbreak of the pandemic differently than large countries. In small countries, labour supply also changed, but trade shocks and uncertainty in financial markets were much of the source of macroeconomic change. Capital adjustment and debt service costs increased.

Appendix

See Table 5

See Figures 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12

Author contributions All authors contributed to the study conception and design. All authors performed material preparation, data collection and analysis. All authors read and approved the final manuscript.

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Data availability https://ec.europa.eu/eurostat. https://unctadstat.unctad.org/datacentre/. https://www.rug.nl/ggdc/productivity/pwt/?lang=en. https://www.brookings.edu/articles/the-external-wealth-of-nations-database/

Code availability Not applicable.

Declarations

Conflict of interest The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this manuscript.

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