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Cardani, Roberta
Croitorov, Olga
Giovannini, Massimo
Pfeiffer, Philipp
Ratto, Marco
Vogel, Lukas

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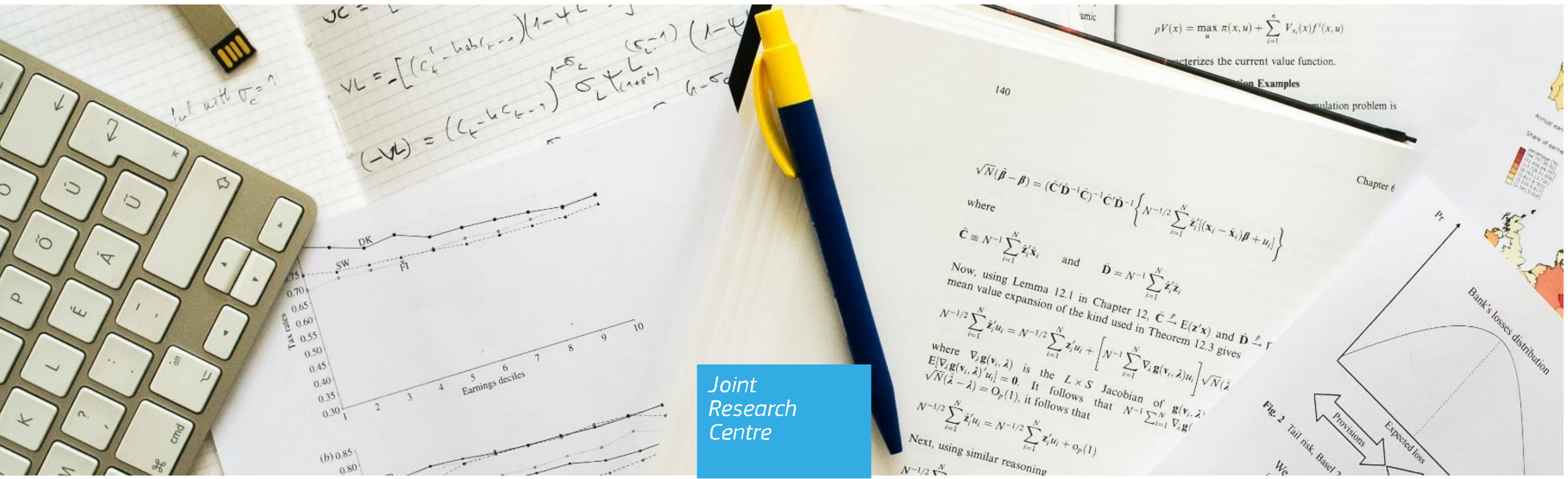

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The Euro Area's pandemic recession: A DSGE-based interpretation*

Roberta Cardani   Olga Croitorov   Massimo Giovannini
Philipp Pfeiffer   Marco Ratto   Lukas Vogel

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Abstract

The COVID-19 pandemic led to a sharp contraction of economic activity in the euro area (and worldwide). Its anatomy differs strongly from other crises in recent history. We analyse the short-term economic effects of the COVID-19 shock through the lens of an estimated DSGE model. We augment the canonical DSGE set-up with 'forced savings' (lockdowns, social distancing), labour hoarding (short-time work) and liquidity-constrained firms to capture salient demand and supply effects of the COVID shock and the containment and stabilisation policies. Shock decompositions with the estimated model show the dominant role of 'lockdown shocks' ('forced savings', labour hoarding) in explaining the quarterly pattern of real GDP growth in 2020, complemented by a negative contribution from foreign and investment demand particularly in 2020q2 and a negative impact of persistently higher (precautionary) savings. The initial inflation response has been modest compared to the severity of the recession.

JEL classification: C11, E1, E20
Keywords: COVID-19, estimated DSGE model, Euro Area, recession, forced savings

*European Commission, DG ECFIN and DG JRC. Corresponding author: Lukas Vogel, lukas.vogel@ec.europa.eu. We thank Björn Döhring, Martin Eichenbaum, Jan in 't Veld, Robert Kollmann, João Leal, Sergio Rebelo, Werner Roeger, Mathias Trabandt and Milan Výškrabka for useful comments and discussions. We are particularly grateful to Lorenzo Frattarolo, Susanne Hoffmann and João Leal for preparing the dataset. The views expressed in this paper are those of the authors and should not be attributed to the European Commission.

1 Introduction

As in other parts of the world, the COVID-19 pandemic has inflicted damage to the European economy that is unprecedented for peacetime. The economic fallout has multiple faces and spans different markets. Supply constraints (lockdowns and social distancing) have led to a contraction of demand in contact-intensive sectors ('forced savings') and in aggregate demand (e.g. Barrero et al. (2020); Guerrieri et al. (2020)). Private consumption and world trade have collapsed, and liquidity squeezes and heightened uncertainty have caused tensions in financial markets. Governments have implemented exceptional fiscal stabilisation packages at the same time.

This paper offers an economic interpretation of the COVID-19 shock through the lens of a structural macro-economic model, focusing on the euro area (EA). The approach disentangles the various factors (lockdown and precautionary savings, investment risk, trade exposure, fiscal policy) and quantifies their respective importance for economic activity since the beginning of the pandemics. To the best of our knowledge, our paper is among the first to present an economic characterisation of the pandemic shock through the lens of an estimated DSGE model for the EA.

The analysis uses the Global Multi-Country model (Albonico et al., 2019) and focuses on shock decompositions (SDs) for economic activity at quarterly frequency. SDs characterise the shocks necessary to fit the rich set of data used for model estimation. The fact that shocks in 2020 have been extremely large by historical standards poses a challenge for the estimation of models with stochastic disturbances. We overcome the problem by including (novel) one-off 'COVID-19 shocks' into the model. These shocks characterise forced savings (generated by social distancing requirements and the closure of non-essential services) and large amounts of labour hoarding. The latter accounts for the gap between hours paid and hours worked, mimicking short-time work schemes. In the baseline version, the identification of the pandemic shocks exploits the fact that we know the timing of the COVID-19 pandemic, i.e. no shock before 2020, similarly to Lenza and Primiceri (2020). Technically, this approach translates into a model with a subset of shocks displaying exogenous deterministic heteroskedasticity. Lifting the identifying restriction, however, reproduces a very similar shock profile. The model also features liquidity-constrained firms with investment demand constrained by the (falling) gross operating surplus.

The model-based SD identifies domestic saving shocks as a key driver of the EA economy's quarterly GDP growth in 2020. Early in the pandemic this findings relates to short-lived 'forced savings', but later increasingly also to persistent saving shocks, reflecting precautionary motives or the fact that restrictions to private demand have become more entrenched (and foreseeable) as the duration of the pandemic increased. Comparison with a model variant without the COVID-specific extensions demonstrates the gain that the extensions bring in terms of model fit.

Our paper is related to Chen et al. (2020), who show that the NY FED's DSGE model augmented by (supply and demand) COVID shocks, interprets the COVID-19 recession as a demand shock to the US economy. Kollmann (2021) argues (for annual data) that in a stylised New Keynesian model an aggregate supply shock is the main driver of the sharp GDP contraction in the EA during the pandemic, whereas both aggregate demand and supply changes matter for the relative stability of inflation. Corrado et al. (2021) estimate a two-sector New Keynesian model to analyse demand and supply contributions. Their model identifies a strong negative demand shock in both sectors, a large labour supply shock to the general sector, and a large labor productivity shock in the pandemic-sensitive sector.

The paper is structured as follows. Section 2 presents stylised facts of the EA macroeconomy during the pandemic. Section 3 outlines the main elements of the model, while Section 4 describes the econometric approach and reports parameter estimates. The propagation of the temporary lockdown shocks is analysed in Section 5. Section 6 provides a structural interpretation and quantitative assessment of the main drivers of (fluctuations of) EA activity growth during recent years and includes a comparison with the Great financial crisis (GFC) of 20008-09. Section 7 compares the estimated lockdown shocks to off-model indicators of mobility and the severity of restrictions to economic activity. Section 8 investigates the robustness of results, notably when lifting the timing assumptions on the 'force saving' shocks. Section 9, finally, summarises the findings and concludes.

2 Stylised facts

Figure 1 summarises a number of stylised facts about the macroeconomic impact of the COVID-19 pandemic in the EA. First, the size of the contraction of economic activity at quarterly frequency in 2020q2 is unprecedented in recent history, including the Global financial crisis (panel a). Second, while real GDP in 2020q3-4 was still lower than in 2019q3-4, the EA economy recovered quickly from the low point in 2020q2, implying strong quarter-on-quarter growth in 2020q3. The V-shape contrasts with the more persistent U-shape of the 2008-09 recession. EA year-on-year growth in 2020q4 has been lower than in 2020q3 though, transforming the V- into a W-shape. Third, private consumption

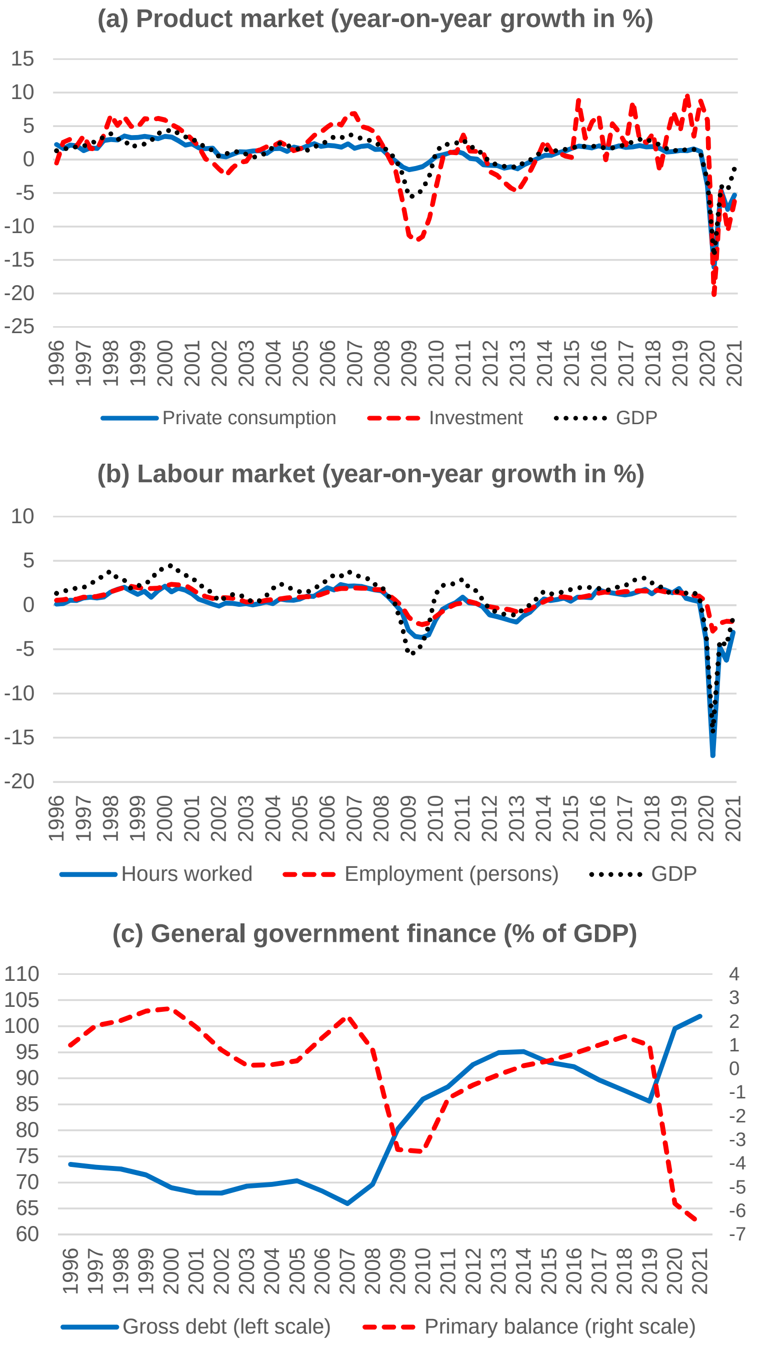


Figure 1: Stylised facts of the COVID recession in the EA economy

Notes: Consumption, investment and GDP are in constant prices, i.e. real terms. Data in panels (a) and (b) are quarterly, whereas data in panel (c) is annual. Data for 2021 in panel (c) corresponds to the European Commission Spring 2021 forecast. *Sources:* AMECO and Eurostat.

and investment in the EA have fallen in tandem and to a similar extent in 2020. This contrasts with investment being more volatile than consumption growth in 'normal' times, and consumption falling less than investment also during the Great recession. Fourth, compared to the dramatic contraction of hours worked in the pandemic (in line with real GDP), the number of persons employed has remained rather stable (panel b), which contrasts with the closer co-movement between hours and persons during the preceding 25 years. The wedge between hours worked and employment in persons points to labour hoarding, notably in the form of short-time work arrangements, during the pandemic. Finally, large fiscal packages during the COVID crisis, with a focus on stabilising income, as well as lower tax revenue have let to a sharp deterioration in the government primary balance (from 1 per cent of GDP in 2019 to -6 in 2020) and an increase in government debt to GDP by almost 15 percentage points (panel c). Our estimated EA model together with the COVID-specific model extensions, which will be described in detail in the subsequent section, has to account for these observations.

3 Model economy

The model outlined in this section is a standard quantitative macro model enriched to capture pandemic-specific features.[1] It features two regions, the EA and the rest of the world (RoW). The EA economy consists of households, a continuum of intermediate goods producers, a final goods firm, import and export sectors, and a government. Wages are sticky and set by trade unions. Perfectly competitive EA final goods producers use EA intermediate goods as well as imported commodities and manufactured goods as inputs. Trade in goods and a financial asset link the EA with the RoW. The RoW block has a simpler structure than the EA economy. The *-superscript denotes RoW variables and parameters. Only the RoW supplies commodities. To provide an empirically plausible account of the macroeconomic environment, the model includes several nominal and real rigidities. Unless stated otherwise, all exogenous random variables follow autoregressive processes of order 1. Time is discrete and indexed by t.

[1]We build on the European Commission's GM model (Albonico et al., 2019; Kollmann et al., 2016), which shares elements with the European Commission's earlier macroeconomic model suite QUEST (Burgert et al., 2020; Ratto et al., 2009). The description here abstracts from linear taxes and introduces only the main exogenous shocks. Appendix A provides a complete account.

3.1 EA production

Perfectly competitive firms produce output (O_t) by combining domestic value added (Y_t) and imported industrial supplies (IS_t) in a CES production function

$$O_t = \left[\left(1 - s_t^{IS}\right)^{\frac{1}{\sigma^o}} \left(Y_t\right)^{\frac{\sigma^o-1}{\sigma^o}} + \left(s_t^{IS}\right)^{\frac{1}{\sigma^o}} \left(IS_t\right)^{\frac{\sigma^o-1}{\sigma^o}} \right]^{\frac{\sigma^o}{\sigma^o-1}}, \tag{1}$$

where s_t^{IS} is the input share of industrial supplies. This share is stochastic and captures fluctuations in the IS intensity of production.[2] $\sigma^o > 0$ is the elasticity of substitution between the two factors. Profit-maximisation implies

$$Y_t = \left(1 - s_t^{IS}\right) \left(\frac{P_t}{P_t^O}\right)^{-\sigma^o} O_t, \tag{2}$$

and

$$IS_t = s_t^{IS} \left(\frac{P_t^{IS}}{P_t^O}\right)^{-\sigma^o} O_t, \tag{3}$$

where P_t and P_t^{IS} are the price of value-added and the price of industrial supplies, respectively. Output prices equal marginal costs

$$P_t^O = \left[(1 - s_t^{IS})(P_t)^{\sigma^o-1} + s_t^{IS}(P_t^{IS})^{\sigma^o-1} \right]^{\frac{1}{1-\sigma^o}}. \tag{4}$$

The commodities are imported from the RoW subject to an excise duty τ^{IS}, so that

$$P_t^{IS} = \mathcal{E}_t P_t^{IS,*} + \tau^{IS} P_t^w, \tag{5}$$

where $\mathcal{E}_t$ is the nominal exchange rate between EA and RoW and P_t^w is the global GDP deflator.[3] Value added Y_t aggregates EA intermediate goods

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{\sigma^y-1}{\sigma^y}} di \right]^{\frac{\sigma^y}{\sigma^y-1}}, \tag{6}$$

[2] Formally, we assume that $s_t^{IS} = s^{IS} \exp(\varepsilon_t^{IS})$, where s^{IS} is the steady-state share of commodity inputs and ε_t^{IS} is an exogenous process.

[3] We measure $\mathcal{E}$ as the price of foreign currency in terms of domestic currency.

where $Y_{i,t}$ denotes intermediate good $i \in [0,1]$. $\sigma^y > 0$ is the elasticity of substitution between varieties $Y_{i,t}$. The production function for good i is

$$Y_{i,t} = \left(A_t^Y N_{i,t}\right)^{\alpha} \left(cu_{i,t} K_{i,t}\right)^{1-\alpha} - A_t^Y \Phi_i, \tag{7}$$

where A_t^Y is an exogenous stochastic technology level, subject to trend and level shocks. $N_{i,t}$, $K_{i,t}$, and $cu_{i,t}$ are firm i's labour input, capital stock, and endogenous capacity utilisation, respectively. Φ_i are fixed costs. Gross investment $I_{i,t}$ drives the law of motion for capital $K_{i,t+1} = K_{i,t}(1-\delta) + I_{i,t}$, with $0 < \delta < 1$.

In light of the restrictions on work, we also augment the model with a transitory 'labour hoarding' shock. This labour demand shock captures short-time work arrangements, i.e. working less while remaining employed. By changing the labour intensity of production at the intensive margin, without hiring or firing costs for the firms, it accounts for the wedge between effective hours worked (production function) and hours paid (wage income). Labour hoarding enters the model as a one-off shock to hours, ε_t^{tN}, and the sum between the shock and hours effectively worked, $N_{i,t}$, represents the hours paid, $N_{i,t}^{paid}$. Period t dividends are:

$$D_{i,t} = P_{i,t} Y_{i,t} - W_t (N_{i,t} + \varepsilon_t^{tN}) - P_t^I I_{i,t} - \Gamma_{i,t}. \tag{8}$$

P_t^I and W_t are the price of investment goods and the nominal wage rate, respectively. $\Gamma_{i,t}$ collects quadratic price and factor adjustment costs. Each firm i sets its price $P_{i,t}$ in a monopolistically competitive market subject to price adjustment costs as in Rotemberg (1982) and the demand function $Y_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{-\sigma^y} Y_t$. A share $(1 - sfp)$ of firms sets prices indexed to past inflation. Appendix A presents the corresponding equilibrium conditions for the firm sector.

Investment liquidity constraints. Following Pfeiffer et al. (2020), we assume that a share of intermediate goods firms faces a temporary liquidity constraint. This time-varying share depends on the aggregate gross operating surplus following the linear relation

$$sli_t = a_0 - a_1 \left(\frac{GOS_t}{K_{t-1}} \frac{P_t}{P_t^I}\right) \tag{9}$$

with parameters a_0 and a_1. We define the firm-specific gross operating surplus as $GOS_{i,t} = Y_{i,t} - W_t/P_t \left(N_{i,t} + \varepsilon_t^{tN}\right)$. We assume that for liquidity-constrained firms $i \in \{0, sli_t\}$, the net investment rate follows

$$\frac{I_{i,t}}{K_{i,t}} - \delta = \mathcal{H}\left(\frac{I_{i,t}}{K_{i,t}}\right) \equiv \zeta_1 \left(\frac{GOS_{i,t}}{K_{i,t-1}} \frac{P_t}{P_t^I}\right) - \zeta_0, \tag{10}$$

where parameters ζ_0 and ζ_1 govern the strength of the liquidity constraint. Pfeiffer et al. (2020) sketch a microfoundation of this functional form based on a model of loan restrictions. Our parametrisation will imply that in the presence of adverse demand or supply shocks a decline of available funds reduces investment demand. With investment decisions of unconstrained firms ($i \in \{sli_t, 1\}$) following a standard Q-equation, denoted $\mathcal{F}(Q_{i,t})$, total private investment follows

$$\frac{I_{i,t}}{K_{i,t}} - \delta = \int_0^{sli_t} \mathcal{H}\left(\frac{I_{i,t}}{K_{i,t}}\right) di + \int_{sli_t}^1 \mathcal{F}(Q_{i,t})\, di. \tag{11}$$

3.2 Trade

Let $Z_t \in \{C_t, G_t, I_t, IG_t, X_t\}$ be the demand of households and the government, private and government investors, and exporters, respectively. Perfectly competitive firms assemble Z_t, using domestic output and imported inputs (M_t^Z) in a CES production function

$$Z_t = A_t^{p,Z}\left[\left(1 - s_t^{M,Z}\right)^{\frac{1}{\sigma^z}} (O_t^Z)^{\frac{\sigma^z-1}{\sigma^z}} + \left(s_t^{M,Z}\right)^{\frac{1}{\sigma^z}} (M_t^Z)^{\frac{\sigma^z-1}{\sigma^z}}\right]^{\frac{\sigma^z}{\sigma^z-1}}, \tag{12}$$

where $A_t^{p,Z}$ denotes a productivity shock in sector Z. $0 < s_t^{M,Z} < 1$ is the sector-specific stochastic import share.[4] $\sigma^z > 0$ is the elasticity of substitution, which is assumed to be common across sectors.

The demand functions for domestic and imported components are

$$O_t^Z = \left(A_t^{p,Z}\right)^{\sigma^z-1}\left(1 - s_t^{M,Z}\right)\left(\frac{P_t^O}{P_t^Z}\right)^{-\sigma^z} Z_t \tag{13}$$

and

$$M_t^Z = \left(A_t^{p,Z}\right)^{\sigma^z-1} s_t^{M,Z}\left(\frac{P_t^M}{P_t^Z}\right)^{-\sigma^z} Z_t, \tag{14}$$

where the price deflator associated with Z_t is

$$P_t^Z = \left(A_t^{p,Z}\right)^{-1}\left[(1 - s_t^{M,Z})(P_t^O)^{1-\sigma^z} + s_t^{M,Z}(P_t^M)^{1-\sigma^z}\right]^{\frac{1}{1-\sigma^z}}, \tag{15}$$

and $P_t^M = \mathcal{E}_t P_t^{X,\star}$.

[4] Thus, $s_t^{M,Z} = s^{M,Z}\exp(\varepsilon_t^{M,Z})$, where $s^{M,Z}$ denotes the steady-state import share of Z.

3.3 Households

Two representative households consume and provide labour to intermediate good producers. A share ω^s of households are savers (s) who own domestic firms and participate in financial markets. Savers maximise welfare

$$E_0 \sum_{t=0}^{\infty} \beta_t \left\{ \frac{(C^s_{j,t} - \varepsilon^{tC}_t - h(C^s_{t-1} - \varepsilon^{tC}_{t-1}))^{1-\theta}}{1-\theta} - \omega^N_t \frac{\left(N^s_{j,t}\right)^{1+\theta^N}}{1+\theta^N} + \frac{\overline{\lambda^s}_t}{P^C_t} \sum_{\mathcal{Q}} B^{\mathcal{Q}}_{j,t}(\varepsilon^{\mathcal{Q}}_t - \alpha^{\mathcal{Q}}) \right\}, \tag{16}$$

subject to

$$P^C_t C^s_{j,t} + B_{j,t+1} = W_t(N^s_{j,t} + \varepsilon^{tN}_t) + D_t + R^r_t B_{j,t} + T^s_{j,t}, \tag{17}$$

where $0 < \theta, \theta^N$. h governs the importance of external consumption habits. β_t and ω^N_t are the stochastic discount factor and a stochastic labour disutility term, respectively.[5] $T^s_{j,t}$ summarises the taxes and transfers, which are detailed in the Appendix.

A novel aspect in this paper compared to the standard GM specification in Albonico et al. (2019) are non-persistent 'forced savings' shocks, ε^{tC}_t, that are zero before 2020 and constrain consumption outside of habit persistence. We discuss these shocks and their macroeconomic transmission in more detail in Section 5.1, given their large estimated contribution to the pandemic recession.

The portfolio $B_{j,t}$ with gross nominal return R^r_t consists of risk-free domestic bonds (rf), one internationally traded asset (bw), and domestic corporate shares (S).[6] We incorporate assets in the utility function with asset-specific risk premium shocks $\varepsilon^{\mathcal{Q}}_t$ with $\mathcal{Q} \in \{bw, S\}$.[7] Asset-specific intercepts, $\alpha^{\mathcal{Q}}$, capture steady-state risk premia except for risk-free assets. Fisher (2015) interprets an increase in $\varepsilon^{\mathcal{Q}}_t$ as a wedge between the return on risky assets and safe bonds.[8]

[5] We define $\beta_t \equiv \beta^t \exp(\sum_{\tau=0}^{t-1} \varepsilon^C_\tau)$, where ε^C_t is an exogenous shock. To ensure a balanced growth path, labour disutility features a multiplicative term $C^{1-\theta}_t$, such that $\omega^N_t = \omega^N \exp(\varepsilon^U_t) C^{1-\theta}_t$ where ε^U_t is exogenous.

[6] As in Benigno (2009) and Ratto et al. (2009), we assume that only the RoW bond is traded internationally.

[7] We follow Krishnamurthy and Vissing-Jorgensen (2012), which incorporate bonds in the utility function. Other estimated macroeconomic models use similar shocks. See, e.g. Christiano et al. (2015), Gust et al. (2017), and Del Negro et al. (2017) for closed economy models. We extend this approach to international and risky assets. Households face a small quadratic adjustment costs for foreign bonds which is rebated as a lump-sum payment.

[8] ε^{bw}_t distorts the first-order condition for the foreign bond and can be expressed as a disturbance to the uncovered interest rate parity condition. These financial shocks also capture the precautionary saving

The remaining households $(1-\omega^s)$ are liquidity-constrained (c) and consume their net disposable income (wages and transfers minus taxes) in each period. Transfer income includes transfers that are proportional to the lockdown shock, lasting for approximately 1.5 years.[9] The budget constraint of liquidity-constrained households is hence

$$P_t^C C_{j,t}^c = W_t(N_{j,t}^c + \varepsilon_t^{tN}) + T_{j,t}^c + P_t^C \left(\varepsilon_t^{tC} - \frac{1}{6} \sum_{i=2}^{7} \varepsilon_{t-i}^{tC} \right). \tag{18}$$

Total consumption and labour supply by EA households are $C_t = (1-\omega^s)\, C_t^c + \omega^s C_t^s$ and $N_t = (1-\omega^s)\, N_t^c + \omega^s N_t^s$, respectively.

3.4 Wage setting

Wage setting is standard along the lines of Ratto et al. (2009) and Kollmann et al. (2016). We assume a monopolistic EA trade union that 'differentiates' homogeneous EA labour hours provided by the two domestic households into imperfectly substitutable labour services. The union then offers those services to local intermediate good firms. The labour input $N_{i,t}$ in those firms' production functions is a CES aggregate of the differentiated labour services. The union sets wage rates at a markup over the marginal rate of substitution between leisure and consumption. The wage markup is inversely related to the substitutability between labour varieties in intermediate good production. We introduce nominal wage rigidity in the form of quadratic wage adjustment costs, captured by parameter γ^w. In addition, parameter γ^{wr} governs real wage rigidity as in Blanchard and Galí (2007) and Coenen and Straub (2005). A share $(1-sfw)$ of unions sets wages indexed to past inflation. The real wage follows

$$\left(mrs_t - \mu_t^w \right)^{1-\gamma^{wr}} \left(\frac{(1-\tau^N)W_{t-1}}{P_{t-1}^{C,vat}} \right)^{\gamma^{wr}} = \frac{W_t}{P_t^{C,vat}}(1-\tau^N), \tag{19}$$

where mrs_t is the share-weighted marginal rate of substitution between consumption and leisure of both households. $P_t^{C,vat} = (1+\tau^C)P_t^C$, where τ^C is a sales tax. μ_t^w denotes the gross wage markup, which fluctuates due to backward-looking wage setting and nominal frictions (see Appendix A).

behaviour of households in the absence of high-order risk. ε_t^S is an investment-specific risk premium shock.

[9] Alternatively, one could argue that even the liquidity-constrained households save some income in the event of 'forced savings' shocks which is then disbursed through additional consumption in subsequent quarters.

3.5 EA government policy

EA monetary policy follows a Taylor-rule (1993) subject to an occasionally binding ZLB constraint. The target interest rate i_t^{not} responds sluggishly to deviations of inflation and the output gap (Y_t^{gap}) from their respective target levels:

$$i_t^{not} - \bar{i} = \rho^i (i_{t-1} - \bar{i}) + (1 - \rho^i) \left[\frac{\eta^{i\pi}}{4} \left(\pi_t^{C,QA} - \bar{\pi}^{C,QA} \right) + \frac{\eta^{iy}}{4} Y_t^{gap} \right], \tag{20}$$

where $\bar{i} = 0.02$. $\pi_t^{C,QA}$ denotes quarterly annualised inflation and $\bar{\pi}^{C,QA}$ its steady state value.[10] Variable i_t is the actual or effective short-term interest rate. ρ^i, $\eta^{i\pi}$, η^{iy} govern interest rate inertia and the response to annualised inflation and output gap, respectively.

The output gap equals the (log) difference between actual and potential output. Potential output at date t is the output level that would prevail if labour input equalled hours worked in the absence of nominal wage rigidity as in Galí (2011), the capital stock was utilised at full capacity, and TFP equalled its trend component.

The target rate equals the effective policy rate i_t only if the former is above the zero lower bound (ZLB). The effective policy rate satisfies

$$i_t = \max\{i_t^{not}, 0\} + \varepsilon_t^i, \tag{21}$$

where ε_t^i is a white noise monetary policy shock.

The fiscal authority raises constant linear taxes on consumption, wage income and corporate profits, the commodity import duty and lump-sum taxes (introduced to close the government budget) to finance its consumptive purchases, investments, and transfers. The individual government expenditure components follow feedback rules.

3.6 EA resource constraint

The resource constraint of the EA economy is

$$P_t Y_t + \tau^{IS} P_t^w IS_t = P_t^C C_t + P_t^I I_t + P_t^{IG} IG_t + P_t^G G_t + TB_t, \tag{22}$$

[10] Quarterly annualised inflation is defined as $\pi_t^{C,QA} = \log\left(\sum_{r=0}^{3} P_{t-r}^{C,vat}\right) - \log\left(\sum_{r=4}^{7} P_{t-r}^{C,vat}\right)$.

where P_t^{IG} and P_t^G denote prices of government investment and consumption goods, respectively, and

$$TB_t = P_t^X X_t - \mathcal{E}_t P_t^{IS,*} IS_t - \sum_z P_t^M M_t^Z \tag{23}$$

defines the trade balance.

3.7 Rest of the world

The RoW block follows a simplified structure. It consists of a production function, a New Keynesian Phillips curve, a consumption Euler equation, a monetary policy rule, and a commodity sector.

Perfectly competitive sectors that bundle the final consumption good C_t^* and the RoW (non-commodity) export good X_t^* follow a structure that is analogous to the determination of EA aggregate demand components outlined in Section 3.2.[11] The export price equals the RoW domestic price times a price shock

$$P_t^{X,*} = P_t^* \exp(\varepsilon_t^{X,*}). \tag{24}$$

Monopolistically competitive RoW intermediate good firms use labour to produce domestic (non-commodity) output with the linear production technology

$$Y_t^* = A_t^{Y,*} N_t^*, \tag{25}$$

where $A^{Y,*}$ is a stochastic productivity trend. Price setting for non-oil output follows a New Keynesian Phillips curve with a cost-push shock. The RoW is a commodity exporter. A competitive sector supplies two distinct commodities co, namely energy (ec) and non-energy (nec) materials, to foreign firms. The supply schedule follows an exogenous stochastic process

$$P_t^{co,*} = \frac{1}{\varepsilon_t^{co}}(1 - \tau^{IS}) P_t^*, \tag{26}$$

where ε_t^{co} is a commodity-specific supply shock.

Preferences of RoW households include external habits

$$E_0 \sum_{t=0}^{\infty} (\beta_t^*) \left\{ \frac{(C_{j,t}^* - h^* C_{t-1}^*)^{1-\theta^*}}{1-\theta^*} \right\}, \tag{27}$$

[11] See equations (12), (13), (14), and (15).

where β_t^* features a discount rate shock $\varepsilon_t^{C,*}$. The consumption habits capture persistence observed in RoW time series for output. Labour supply of RoW households is assumed to be inelastic. Monetary policy in the RoW follows an interest rate rule analogous to equation (20).

4 Data and econometric approach

Data. We estimate the model on quarterly data, starting with the introduction of the euro in 2000q1 and until 2019q4. Based on the estimated parameters, we then identify the structural shocks during the pandemic with data spanning until 2021q1. The EA data (quarterly national accounts, fiscal aggregates, quarterly interest and exchange rates) are taken from Eurostat. We construct RoW series based on the IMF International Financial Statistics (IFS) and World Economic Outlook (WEO) databases.[12]

Calibration. We calibrate a subset of parameters to match long-run data averages or targets. All real variables grow at the average growth rate of EA GDP (1.3%). Price level trend growth corresponds to the targeted inflation rate of 2% per year. The steady-state ratios of main economic aggregates to GDP match historical averages. The discount factor of 0.998 (quarterly) implies an annual interest rate of 1%. The share of savers is 0.67. The Cobb-Douglas labour share, α, equals 0.65. We calibrate the shares of import content in aggregate demand components, $s^{M,Z}$, as in Bussiere et al. (2013).[13] The share of commodities, s^{IS}, matches the average of imported commodities to GDP (0.04). The share of the energy component, s^{ec}, corresponds to the average share of oil in total imported commodities (0.59).

Posterior estimates. We estimate the remaining parameters using non-linear Bayesian full information methods to account for the ZLB constraint (see Giovannini et al. (2021)). Table 1 reports estimates for a number of key parameters. The Appendix B presents the estimates for the remaining parameters. On the household side, relatively high consumption habits suggest a smooth consumption response to changes in income for savers. Risk aversion and the inverse labour supply elasticity are 1.73 and 2.9, respectively. These estimates are similar to the literature (see, e.g., Kollmann et al. (2016)). Regarding trade, the posterior mode of the import price elasticity is 1.39. We estimate a low price elasticity

[12] We also include prices of two main commodities, mineral fuels and raw materials, from Eurostat Comext data. Appendix B provides additional details on the data sources and aggregation.

[13] Appendix B provides the corresponding values.

		Prior distribution			Posterior distribution		
		Distr.	Mean	Std.	Mode	10%	90%
Preferences							
Consumption habit persistence	h	Beta	0.50	0.10	0.86	0.79	0.89
Risk aversion	θ	Gamma	1.50	0.20	1.73	1.56	2.30
Inverse Frisch elasticity of labor supply	θ^N	Gamma	2.50	0.50	2.90	2.21	3.58
Import price elasticity	σ^z	Gamma	2.00	0.40	1.39	1.17	1.64
Oil price elasticity	σ^o	Gamma	0.50	0.08	0.33	0.31	0.38
Nominal and real frictions							
Price adjustment cost	γ^P	Gamma	60.00	40.00	31.39	22.54	39.74
Nominal wage adjustment cost	γ^w	Gamma	15.00	3.00	15.07	11.62	21.31
Real wage rigidity	γ^{wr}	Beta	0.95	0.02	0.94	0.91	0.96
Share of forward looking price setters	sfp	Beta	1.00	0.05	0.99	0.92	1.00
Share of forward looking wage setters	sfw	Beta	0.50	0.20	0.93	0.81	0.98
Steady state share of liquidity constrained firms	$\overline{sli}$	Beta	0.2	0.08	0.16	0.06	0.27
Strength of the liquidity constraint	ζ_1	Beta	0.1	0.04	0.087	0.03	0.12
Demand shock processes							
Subjective discount factor - AR(1) coeff.	ρ^C	Beta	0.50	0.20	0.75	0.35	0.80
Time preference - std.	ε^C	Gamma	0.01003	0.0040	0.0010	0.0041	0.0132
Investment risk prem. - AR(1) coeff.	ρ^S	Beta	0.50	0.20	0.91	0.89	0.95
Investment risk prem. - std.	ε^S	Gamma	0.0075	0.0043	0.0049	0.0016	0.0076
RoW region							
Habit persistence	h^*	Beta	0.70	0.10	0.86	0.79	0.89
Risk aversion	θ^*	Beta	1.50	0.20	1.73	1.56	2.30
Import price elasticity	σ^{C^*}	Gamma	2.00	0.40	1.12	1.06	1.19

Table 1: Prior and posterior distribution of key estimated model parameters.

of EA commodity demand at around 0.33. Our posterior estimates also suggest sticky prices and wages, including a high share of forward-looking price and wage setting. Key demand shocks are highly serially correlated. Estimated consumption habits are similar in the RoW and in the EA. The steady-state share of liquidity-constrained firms ($\overline{sli}$) is estimated at 15%. The estimated response parameter ζ_1 implies that changes in the gross operating surplus partially drive private investment dynamics.[14]

5 Propagation of key shocks

This section presents impulse response functions (IRFs) for key shocks to better understand the dynamics of the model given the parameter estimates. In particular, Section 5.1 highlights the specificity of the lockdown ('forced savings') shock compared to the standard savings (time preference) shock. Furthermore, we discuss the transmission of investment risk, labour hoarding, wage markup, and trade shocks, which are also prominent in the shock decompositions presented in the subsequent section. In light of our focus on the pandemics, we consider a scenario in which the ZLB on short-term nominal interest rate in the EA binds for one year. In particular, the IRFs are initialised at the state of 2019q4. Shock sizes are normalised to one standard deviation.

5.1 Lockdown shocks

Figure 2 illustrates the transmission of the non-persistent 'forced savings' shock compared to the standard savings (time preference) shock in the model. The non-persistent 'forced savings' shock lowers consumption for one period. Lower consumption demand, together with firm financing constraints and the absence of monetary stimulus, also reduce investment demand. Real GDP declines temporarily, whereas employment remains largely unchanged given the adjustment costs at the extensive margin. The trade balance increases in the short run due to lower domestic and import demand, and the government primary balance deteriorates in response to lower tax revenue and growing benefit payments. The economy's initial response to the standard saving shock is qualitatively similar. The standard shock is subject to habit persistence, however, which leads to a hump-shaped pattern in domestic demand. In addition, the standard saving shock itself is persistent and still active when the economy exits the ZLB environment after four quarters. The central bank then reacts with a policy rate reduction in the medium term,

[14] The calibration of ζ_0 and a_0 follows endogenously from the steady-state relations based on equations (9) and (10). At first-order, parameter a_1 does not affect model dynamics.

which stabilises private investment, and which leads to a depreciation of the domestic currency, with positive repercussions for the trade balance. An important characteristic of the non-persistent saving shock is the minimal impact on inflation. Contrary to the persistent saving shock, the one-period shock has no longer-lasting impact on inflation expectations, an important determinant of actual inflation in the New Keynesian Phillips curve.

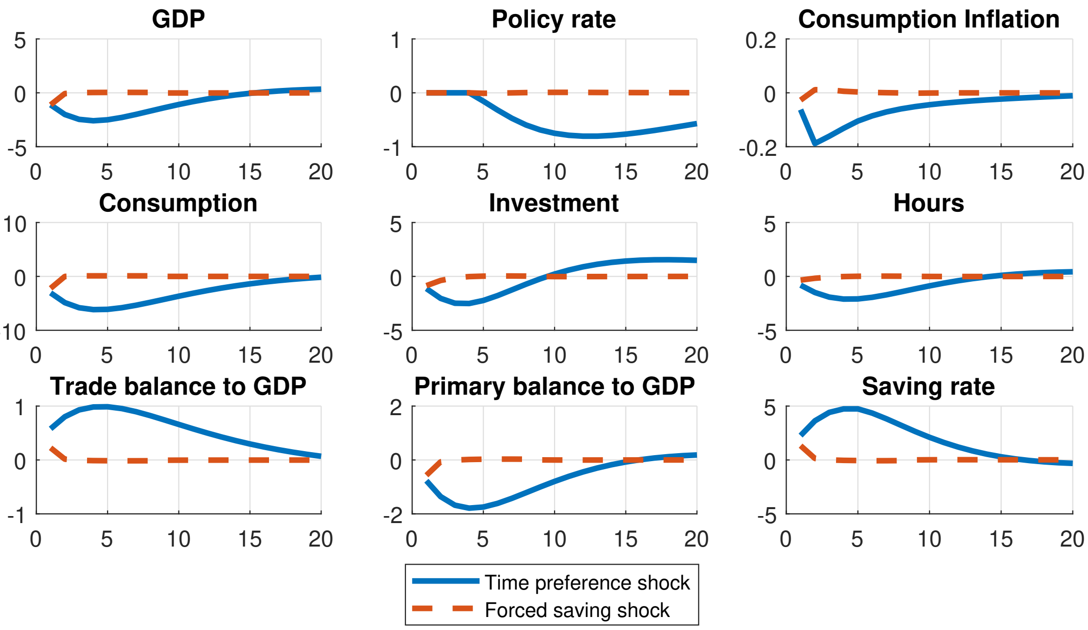


Figure 2: Dynamics of transitory ('forced') and persistent saving shocks

Notes: All variables are displayed in percent deviations from steady state, except for the trade balance relative to GDP, the government primary balance relative to GDP and the household saving rate, which are expressed in percentage-point deviations from steady state instead. Periods correspond to quarters. The two shocks are normalised to have a similar GDP response on impact.

Figure 3 compares the non-persistent labour hoarding shock as second lockdown-specific shock to the 'forced savings' shock from Figure 2. The labour hoarding shock is a non-persistent shock to labour demand. Hours worked decline. But contrary to a standard labour supply shock, labour hoarding does not increase the real wage. Investment falls because the marginal return to capital declines with falling labour intensity, and because of liquidity-constrained investment. The savings rate declines temporarily due to lower household income. Inflation increases temporarily because of an increase in the marginal costs of producing.

In sum, IRFs for the lockdown shocks show qualitative characteristics that make them suitable candidates for explaining salient features of the pandemic period as presented in

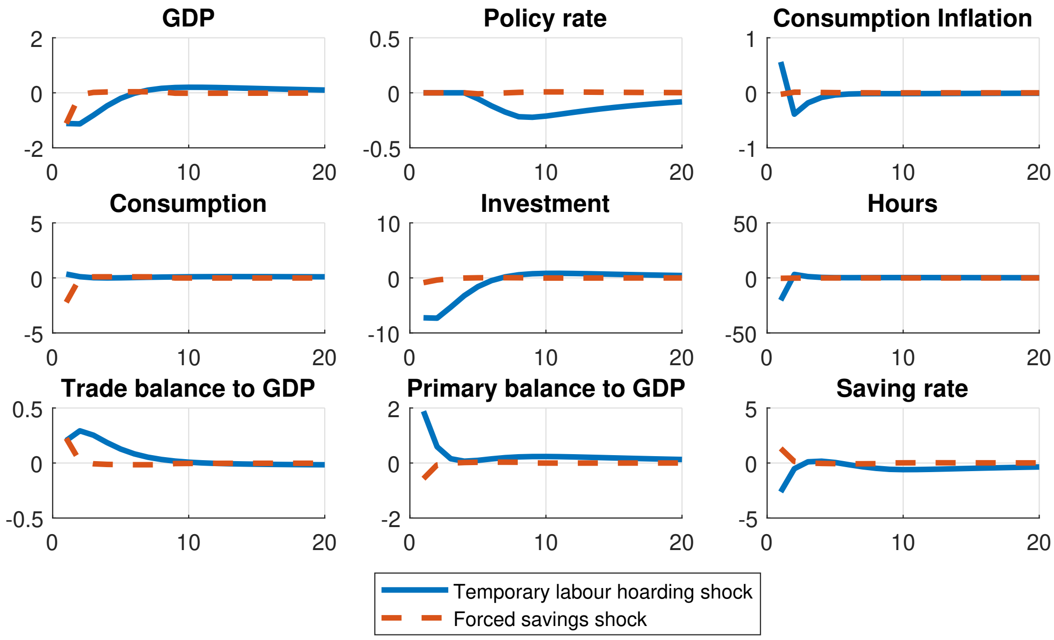
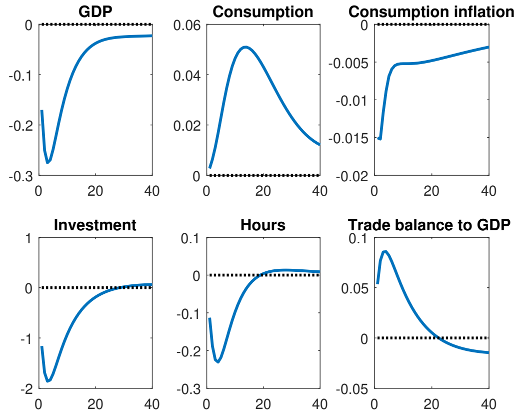


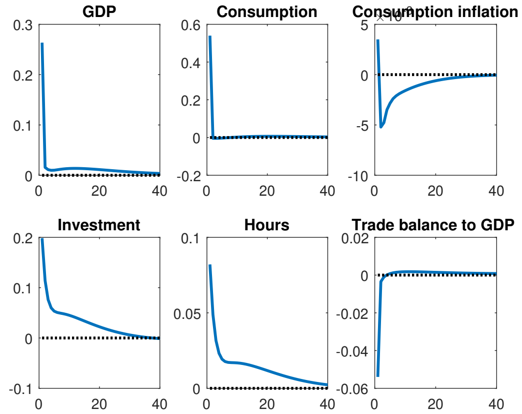
Figure 3: Dynamics of transitory ('forced') saving and labour hoarding shocks

Notes: All variables are displayed in percent deviations from steady state, except for the trade balance relative to GDP, the government primary balance relative to GDP and the household saving rate, which are expressed in percentage-point deviations from steady state instead. Periods correspond to quarters. The left axis (blue line) shows the response to a temporary lockdown shock (forced saving shock). The right axis (red line) shows the response to a temporary labour hoarding shock.

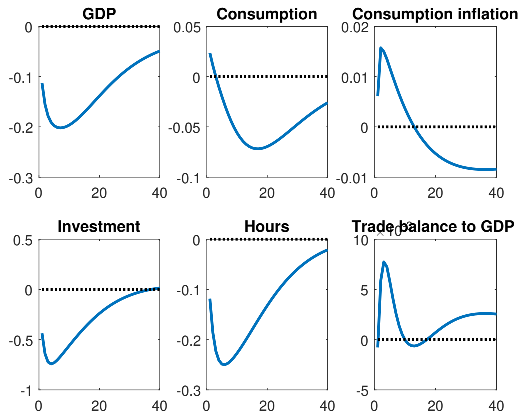
Figure 1. In particular, 'forced savings' generate a sharp decline in consumption demand, followed by a swift recovery, a simultaneous decline in private investment, a drop in total economic activity, and a deterioration in the government fiscal balance (increase in the government debt-to-GDP ratio). The labour hoarding shock can capture the large gap between effective hours worked and official employment during the pandemic. Neither the transitory savings nor the labour hoarding shock implies a (significant) decline in inflation. Both shocks increase the EA trade balance, which is not found in the data. Hence, additional shocks are necessary to replicate the information from the rich data set in quantitative terms according to the model estimation. Other key drivers of EA economic activity during the pandemic are briefly characterised in Section 5.2.



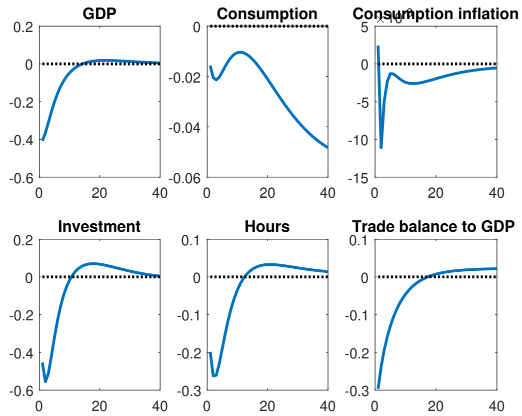
(a) Risk premium



(b) Temporary transfers



(c) Wage markup



(d) RoW openness

Figure 4: IRFs of key shocks

Notes: All variables are displayed in percent deviations from steady state, except for the trade balance to GDP, which is expressed in percentage-point deviation. Periods on the x-axis are quarters.

5.2 Other main shocks

Figure 4 summarises IRFs for four other shocks that the model estimation identifies as relevant drivers of macroeconomic dynamics during the COVID-19 pandemics, as we will discuss in Section 6 below. The risk premium shock in panel (a) is a temporary increase in investment risk, with the estimated degree of persistence. Increasing investment risk (financing costs) lowers investment demand. Real GDP and employment decline. Note that the decline in real GDP is very persistent as reduced investment and a lower capital stock shrink production potential in the medium and longer term. Net exports increase temporarily because of lower import demand and real effective depreciation. Consumption, to the contrary, increases to some extent, given that saver households switch away from investment and increase consumption expenditure instead.

Panel (b) characterises a temporary increase in government transfers. Consumption increases, driver by stronger spending from hand-to-mouth households. Net exports decline, driven by growing import demand. Investment increases together with consumption and activity, which is due to stronger investment by financially-constrained firms.

The wage markup shock in panel (c) increases wage claims for given labour demand and consequently leads to a decline in hours worked and real GDP. Investment also declines due to the firms' financing constraints and the fact that the drop in employment lowers the marginal return to capital. Consumption increases initially due to the temporary increase in the wage sum but declines thereafter in line with falling total income.

Finally, the RoW openness shock in panel (d) reduces the degree of trade openness in RoW, which implies a decline in the demand for EA exports. The trade balance, economic activity and employment in the EA decline in response. Persistently weaker exports also lower investment demand as the firms' financing constraint tightens. Consumption declines mildly, driven by the negative impact of falling employment on the disposable income of liquidity-constrained ('hand-to-mouth') households.

6 Quantifying growth drivers during the pandemic

This section focuses on the main drivers of EA economic activity, inferred from shock decompositions (SDs) of real GDP growth at a quarterly frequency. The SDs attribute the dynamics of endogenous variables to the various estimated exogenous shocks. In order to play an important role in the SDs, a shock must capture important data patterns not only for the particular variable of interest but also for the entire set of observables. In particular, our rich two-region model informs about the quantitative importance of domestic demand and supply factors as well as global economic conditions.

Subsection 6.1 presents results from the augmented model version described in section 3, which includes the lockdown ('forced savings', labour hoarding) shocks as well as liquidity-constrained firms. This is done, similarly to Lenza and Primiceri (2020), by imposing a deterministic heteroskedasticity to the subset of COVID-related white noise shocks for the periods 2020q1-2021q1. By doing so, we allow at each point in time a different shock-specific propagation mechanism while maintaining normalised distributed errors. Subsection 6.2 contrasts the findings to a SD of GDP growth from the 'pre-COVID' model as in Albonico et al. (2019), i.e. the GM model without COVID-specific features (no transitory lockdown shocks).

6.1 Model with lockdown shocks

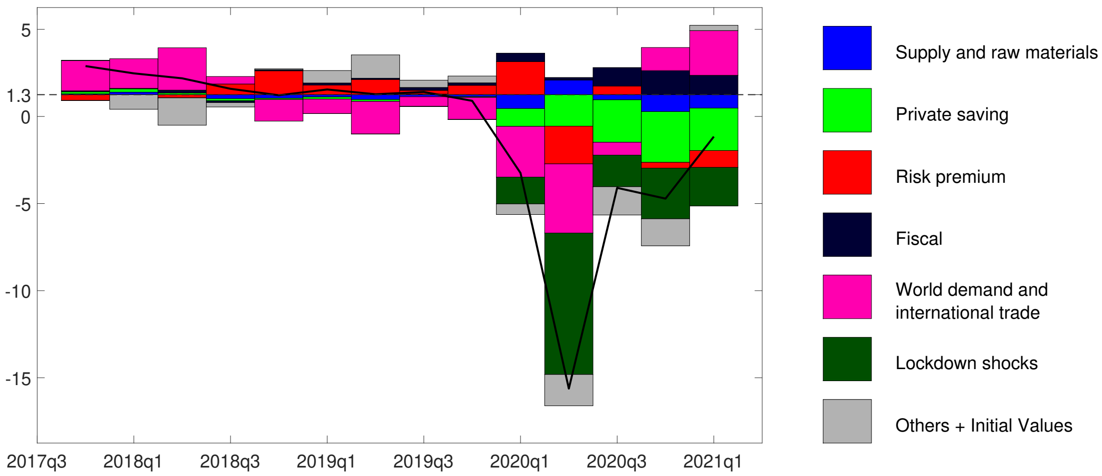


Figure 5: EA real GDP growth (per cent, year-on-year)

Notes: The figure shows the shock decomposition of year-on-year real GDP growth from 2017q3-2021q1. All structural shocks together recover the observed time series of GDP growth (continuous black line). We have grouped the estimated shocks into seven broad categories: (1) supply shocks and raw materials, including TFP, price and wage markup shocks (blue); (2) persistent private saving shocks (light green); (3) investment risk premium shocks (red); (4) discretionary fiscal policy shocks, which capture deviations from estimated fiscal policy rules (black); (5) shocks to world demand and international trade, which include foreign demand and supply shocks as well as deviations of trade volumes and prices from the estimated export and import demand and pricing equations (pink); (6) lockdown shocks since 2020 ('forced saving' shock, labour hoarding shock) (dark green); (7) other remaining factors (grey).

Figure 5 provides a model-based quantitative assessment of the drivers of year-on-year real GDP growth over the period 2017q3-2021q1. The lockdown shocks (particularly 'forced savings') have been the dominant driver of the 2020 recession, with a strong contraction in 2020q2, an easing in 2020q3 (improvement compared to 2020q2), and a renewed deterioration in 2020q4 that carries over to 2021q1.[15] A persistent increase in saving ('private savings' in Figure 5) has also contributed to making the massive decline in private consumption the most important driver of the 2020 recession. Its role has increased in the second half of 2020. The persistent saving shock may reflect precautionary savings. In particular, elevated uncertainty about the course of the pandemic and its economic impact over different horizons may have strengthened precautionary motives. It furthermore reflects the fact that restrictions have become more entrenched given the

[15]The seemingly better growth performance in 2021q1 compared to 2020q4 derives from the contraction in 2020q1, which is the point of comparison for year-on-year growth in 2021q1. Figure 6 shows that there is no improvement between 2020q4 and 2021q1 on a quarter-on-quarter basis.

persistence of the pandemic. The pandemic's impact on global demand and trade has been a third important driver of GDP growth, with falling export demand and some offsetting from stronger home bias on the import side. Falling investment demand ('risk premium') added to the contraction of economic activity mainly in 2020q2. Standard supply factors, in comparison, have played a minor role for explaining GDP growth, with a positive contribution from falling commodity prices in 2020q2. Fiscal stimulus has been an upside force on GDP growth in 2020, where Figure 5 shows the impact of discretionary fiscal shocks, which complement the working of automatic stabilisers in the model. The contribution of (discretionary) fiscal shocks remains moderate in quantitative terms, however, given the nature of the stimulus, i.e. mainly transfers in an environment (moderate share of hand-to-mouth consumers) in which the transfer multiplier is modest.

To compare the COVID-19 recession to the global financial crisis (GFC) of 2008-9, Figure 6 zooms into both episodes with SDs of quarter-on-quarter (q-o-q) real GDP growth. An obvious difference relates to persistence. The GFC recession in panel (a) was characterised by negative q-o-q growth rates in 2008, reaching a minimum in 2009q1, before reverting to trend growth in 2009q2 (and followed by a second recession in 2012-13 in the EA). The pandemic recession in panel (b), to the contrary, is marked by a much steeper decline of GDP growth during the first half of 2020, which reverts into strong positive q-o-q growth in 2020q3 and than stagnates again in 2020q4 and 2021q1.

The two episodes in Figure 6 also differ with respect to the main drivers. According to the model estimates, falling world demand and international trade, falling investment demand and appreciation pressure on the euro explain a large part of the GFC recession. Monetary easing, fiscal expansion, and import substitution (a shock that the model requires to match the contraction of international trade faster than the decline in world demand) mitigated the depth of the recession. The growth rate normalisation in 2009q2 followed primarily from recovering world demand and easing investment risk (financing costs). The SD for the pandemic recession, to the contrary, assigns a much larger role to domestic consumption, notably the transitory ('forced') saving shock. The latter is the largest individual factor behind the slowdown in the first half of 2020 and, due to the easing of lockdown and distancing measures over the summer months, behind the partial recovery in 2020q3. Other important drivers are the decline in world demand and trade and the increase in investment risk, which both eased in 2020q3. Discretionary fiscal policy, defined as the deviation from fiscal feedback rules, has made a positive overall contribution to GDP growth since mid-2020.

The SD for EA consumer price inflation (Figure 7) highlights different drivers than the

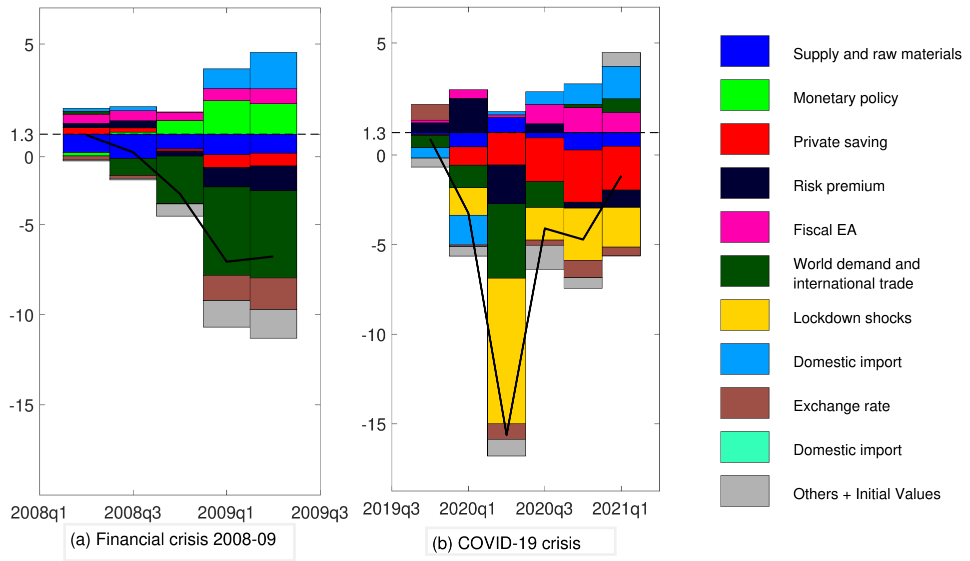


Figure 6: EA real GDP growth in GFC and COVID-19 recessions (per cent, year-on-year)

Notes: The panels show shock decompositions of quarterly real GDP growth in the EA during the Great financial crisis and the COVID-19 crisis recession. All structural shocks together recover the observed time series of GDP growth (continuous black line). We have grouped the estimated shocks into nine broad categories: (1) supply shocks and raw materials, including TFP, price and wage markup shocks (blue); (2) monetary policy (light green); (3) private saving shocks (red); (4) investment risk premium shocks (black); (5) discretionary fiscal policy shocks, which capture deviations from estimated fiscal policy rules (pink); (6) shocks to world demand and international trade, which contain foreign demand and supply shocks as well as deviations of trade volumes and prices from the estimated export and import demand and pricing equations (dark green); (7) lockdown shocks since 2020 ('forced saving' and temporary labour hoarding shocks) (yellow); (8) exchange rate shocks, (9) shocks to the share of imports ('home bias') in the EA (light blue); (10) any remaining factors (grey).

SD for GDP growth. Transitory lockdown shocks have little impact on current inflation despite strong negative output effects because they do not alter inflation expectations. Persistent negative saving shocks ('private saving'), in contrast, lower inflation expectations, which leads to a lower actual inflation. Persistent negative shocks to world demand and international trade have a similar effect.

Positive contributions from 'supply and raw materials', notably labour cost and price markup shocks, partly offset these downside factors. The former mirror an increasing wedge between wages and labour productivity, the latter fill the gap between inflation and its fundamental drivers.[16] The decline of commodity prices, to the contrary, has

[16]Re-weighting of the consumption basket for inflation measurement is likely to affect the output-inflation nexus in our one-sector model. The GDP contraction in the pandemic has been concentrated in certain sectors for which the weights in the consumption baskets have been lowered at the same time (Claeys and Guetta-Jeanrenaud, 2021).

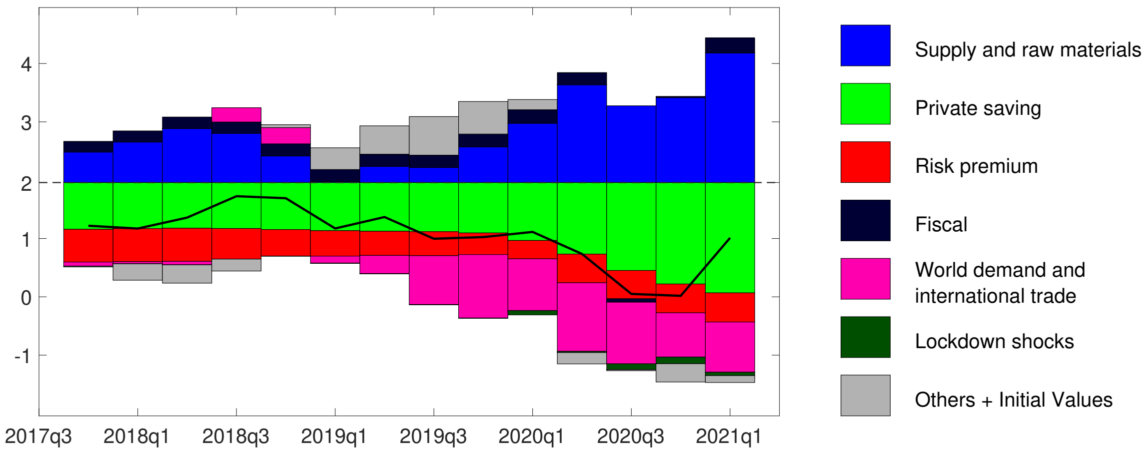


Figure 7: EA HICP inflation (per cent, year-on-year)

Notes: Inflation rates are year-on-year, i.e. they measure HICP level growth relative to the same period of the previous year. Units on the y-axis are % (1=1%). The solid black line represents the data. Bars below (above) the dashed line (trend inflation) indicate negative (positive) contributions to HICP inflation. All structural shocks together recover the observed time series of GDP growth (continuous black line). Estimated shocks are grouped into seven broad categories: (1) supply shocks and raw materials, including TFP, price and wage markup shocks (blue); (2) persistent private saving shocks (light green); (3) investment risk premium shocks (red); (4) discretionary fiscal policy shocks, which capture deviations from estimated fiscal policy rules (black); (5) shocks to world demand and international trade, which contain foreign demand and supply shocks as well as deviations of trade volumes and prices from the estimated export and import demand and pricing equations (pink); (6) lockdown shocks since 2020 (transitory 'forced' saving and labour hoarding shocks) (dark green); (7) other remaining factors (grey).

contributed to lower inflation in 2020, while it has increased consumer prices in 2021q1. The positive effect of expansionary fiscal policy on HICP inflation is offset in 2020q3-4 by the temporary VAT reduction in Germany (July-December 2020), which we include in the model together with the Bundesbank (2020) evidence on the pass-through to consumer prices.[17]

6.2 Model without lockdown shocks

What is the value-added of COVID-specific model extensions compared to the pre-COVID specification ('standard model') in Albonico et al. (2019)? How do the model extensions (lockdown shocks) affect the economic interpretation of the pandemic recession and, possibly, projections of an economic recovery? This section provides some answers by com-

[17]In particular, the VAT reduction amounts to an average 1.8 pp tax cut for the HICP basket. Short-term pass-through into consumer prices is 60 per cent. And Germany accounted for 29 per cent of EA-19 private consumption expenditure in 2020.

paring SDs for EA real GDP growth (quarter-on-quarter) from the two variants of the model, i.e. the model without the pandemics-related shocks versus the model version with the COVID-specific extensions.

Figure 8 shows the results from the two variants of the model. The two pictures look similar with respect to the role of foreign and investment demand. There are important differences concerning exchange rate developments and the domestic drivers, however. First, the augmented model attributes a large part of the drop in consumption in 2020q1-2 to the 'forced savings' shock, i.e. lockdown and social distancing measures that reduce demand and supply. The 'forced savings' shock is non-persistent, however, so that it can account for the partial recovery of consumption in 2020q3. Similarly, in a forecasting context, one can expect consumption to recover quickly after a lockdown shock ('pent-up demand'). Without the lockdown shocks, to the contrary, panel (a) explains the drop in consumption by the standard ('voluntary') saving shocks, i.e. a decline in the rate of time preference. The standard saving shock is persistent, and consumption responds with strong habit persistence. A persistent saving shock (precautionary or entrenched restrictions) is less compatible with a quick recovery in consumption demand, as illustrated in Figure 2 above. Instead, the standard model in panel (a) implies large exchange rate and, to a lesser extent, wage markup shocks. The exchange rate shocks in (a) are needed to reconcile observed exchange rates with the expected future path of (real) interest rates. The wage markup shocks dampen the real disposable income of households as an additional force to match lower consumption demand.

6.3 Forecast revisions

Another way of looking at the pandemic's macroeconomic ramifications is the analysis of forecast errors, as suggested by Kollmann (2021). COVID-19 has been a very large exogenous shock and arguably the primary driver of revision to the EA forecast for 2020-21. Figure 9 provides a shock decomposition of the forecast error for real GDP growth. More precisely, it decomposes the difference between EA real GDP growth up to 2021q1 (year-on-year) as reported in July 2021 and the corresponding series from the European Commissions Autumn 2019 forecast (European Commission, 2019).[18]

Figure 9 paints a picture that is very similar to the one in Figure 5. The lockdown

[18] In principle, differences between the two series may reflect not only forecast error but also revised historical data. Revisions of historical data between Autumn 2019 and mid-2021 have been minor (practically negligible) compared to the forecast error, however. The model-based decomposition takes account of forecast errors for the large set of variables included in the Commission forecasts, i.e. not only GDP growth.

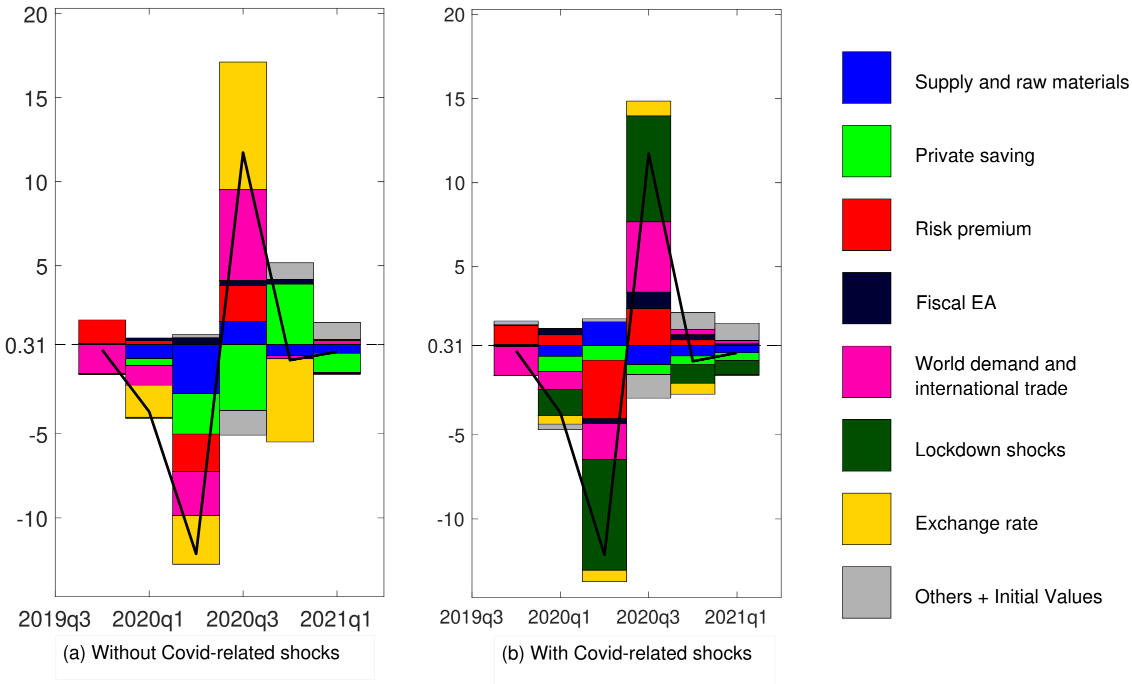


Figure 8: EA real GDP growth across model variants (per cent, quarter-on-quarter)

Notes: The two panels show shock decomposition of real GDP growth in the EA (quarter-on-quarter) in a model (a) without and (b) with COVID-specific shocks and extensions. See Figure 6 for additional details on the shock grouping.

shocks are the main drivers of the COVID-related forecast error, together with an upward revision of persistent savings (persistent downward revision of private consumption growth), and negative surprises for world demand and trade as well as investment demand ('risk premium') notably in 2020q2. Discretionary fiscal policy has been more expansionary than expected before the pandemic shock, which explains the positive contribution of fiscal shocks to growth revisions for the second half of 2020 and early 2021.

7 Lockdown shocks in model and data

The decomposition of macroeconomic dynamics in estimated DSGE models relies on the set of estimated shocks. The latter often remain rather abstract and difficult to interpret or compare to real-world equivalents. An example is the investment risk shock in our model, which describes a wedge between actual investment demand and the investment demand compatible with average financing costs and expected future demand and returns to capital. The wedge can have different interpretations, e.g. increased investor

Figure 9: Forecast error for EA real GDP growth (per cent, year-on-year)

Notes: The chart shows the forecast error as the difference between EA real GDP growth (year-on-year) reported in July 2021 and the forecast for EA real GDP growth (year-on-year) from Autumn 2019. Units on the y-axis are percentage points (1=1pp forecast error). The solid black line shows the forecast error. Bars below (above) the zero line indicate negative (positive) contributions to the forecast error. The grouping of shocks corresponds to Figure 5.

risk aversion, an increase in corporate financing costs over safe interest rates, or quantitative restrictions on credit volumes. Kollmann et al. (2016), e.g., illustrates the close co-movement between estimated EA and US investment risk shocks and indicators of credit tightness during 2000-14.

Here we compare the transitory 'forced saving' shock, which is the most important individual driver of the quarterly profile of the 2020 recession according to our model, to some out-of-sample measures of fit. In particular, Figure 10 plots the estimated profile of the transitory 'forced savings' shock together with empirical measures of lockdown stringency and mobility restrictions. The profiles are very similar, including particularly close co-movement between the estimated shock and the mobility indicator, in the first half of 2020. The co-movement suggests that 'forced savings' in the model reflect contact restrictions and supply constraints. Consumption recovers more than the restriction and mobility indices in the second half of 2020. However, the indicators and the estimated shock move in parallel during the renewed deterioration of the epidemiological situation in late 2020 and early 2021.

Figure 11 plots short-time work as measured by government wage subsidies in the data

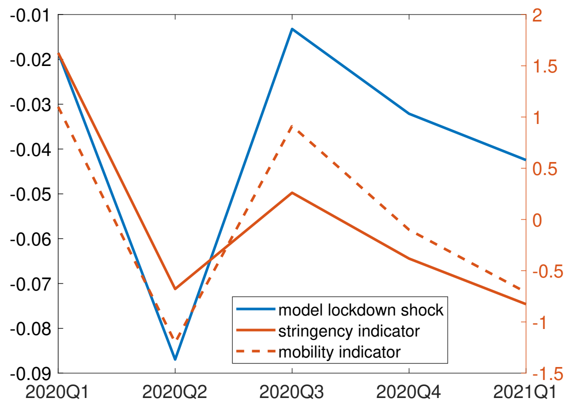


Figure 10: Lockdown indicators

Notes: The model shock (blue line and left axis) corresponds to the estimated 'forced savings' shock as described in equation (16). The data are standardised time series of the Oxford stringency index (Hale et al., 2020) and Google's mobility indicator aggregated across EA countries (red lines and right axis).

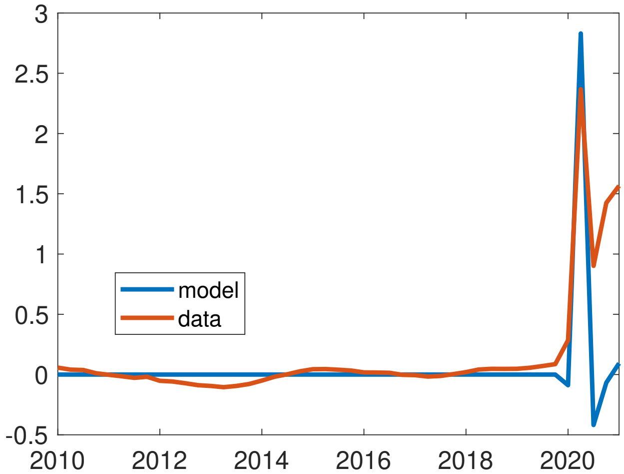


Figure 11: Lockdown indicators in model and data

Notes: The data correspond to demeaned subsidies (on labour) received by the employer as a share to GDP. The model shock corresponds to the estimated 'labour hoarding shock' as shown in equation (8).

and the labour hoarding shock in the model, which has been introduced to account for the discrepancy between the strong decline in actual hours worked and relatively stable employment in persons in the EA during the pandemic. Both series move closely together in the first half of 2020. However, starting in 2020q3, both figure 11 and figure 10 show a level shift disconnecting the model estimated lockdown shocks from lockdown indicators. According to the model's results, lockdown shocks no longer played a major role in the second wave, and drag in growth has been mostly driven by more persistent negative structural shocks, which suggests a building up uncertainty around the evolution of the COVID pandemic and related restriction measures.

8 Robustness checks

The transitory 'forced saving' shock plays a major role in explaining the EA GDP growth pattern during the COVID-19 crisis. In this section, we analyse the robustness of this result for alternative specifications of COVID-related shocks. First, we allow the forced saving shock to be present over the whole span of our data and check whether it replicates the shock pattern of the benchmark model during the COVID-19 crisis without altering the pre-2020 results. Second, we consider an alternative specification of the lockdown consumption shock, namely a temporary time preference shock with moving average structure, and discuss implications for the GDP forecast and shock decomposition.

8.1 Lockdown shocks in the full sample

In the benchmark model, for which results were presented in Section 6, the transitory forced saving shock enters with large standard deviation only in 2020q1.[19] Figure 12 plots the smoothed innovations starting from 2000q1. The resulting shock profile for the benchmark model corresponds to the red line. To test the appropriateness of imposing heteroskedasticity in the shock with zero standard deviation until 2019q4, we estimate a model variant including the transitory forced saving shock and then extend it with the estimated standard deviation into 2020 (homoskedastic shock assumption). The estimated standard deviation of the forced savings shock during 2000q1-2019q4 is 25 times smaller than the calibration imposed in the benchmark model. The blue line in Figure 12 shows the profile of the estimated forced saving shock.

The profile of the in-sample estimated shock (blue line) suggests that transitory forced saving (consumption) shocks have played little role prior to 2020. The estimated profile looks like a white noise shock and does not show any pre-2020 spike that would be comparable in magnitude to the 2020 amplitude. In particular, the forced saving shock shows no comparable spike around the Global financial crisis in 2009 or the EA sovereign debt crisis in 2012. Extending the estimated shock into 2020, we see that, starting in 2020q1, the estimated innovation has a time profile that is very similar to the COVID-specific

[19] As in Lenza and Primiceri (2020), we impose a deterministic heteroskedasticity to the forced saving shock in the benchmark model, which has a standard deviation of zero until 2019q4, and 0.04 starting in 2020q1, as reported in Tables 3 and 4 in the Appendix.

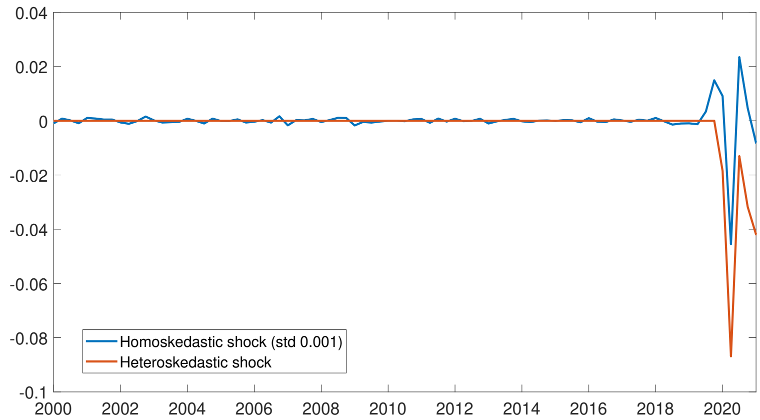


Figure 12: Smoothed estimates of forced saving innovations

Notes: Red solid line refers to the benchmark model (no 'forced saving' shock prior to 2020) and the blue one to the model with estimated homoskedastic 'forced saving' shock.

forced saving shock in the benchmark model. The smaller estimated standard deviation constrains the size of the forced savings shock in 2020. But despite the smaller estimated standard deviation, the innovation in 2020q2 is still half as large as in the benchmark model. The comparison confirms that the relevance of the transitory forced savings shock in the model is particular to the COVID-19 crisis.

8.2 An alternative specification of the 'forced saving' shock

The benchmark model contains three different saving shocks. In equation (16), ε_t^{tC} is the transitory forced saving shock that is not constrained by habit persistence, whereas ε_t^C is a persistent shock to the rate of time preference that is subject to habit persistence and has itself two components: a very persistent preference shock capturing 'secular stagnation' trends, and a less persistent one capturing more cyclical shifts in private savings.

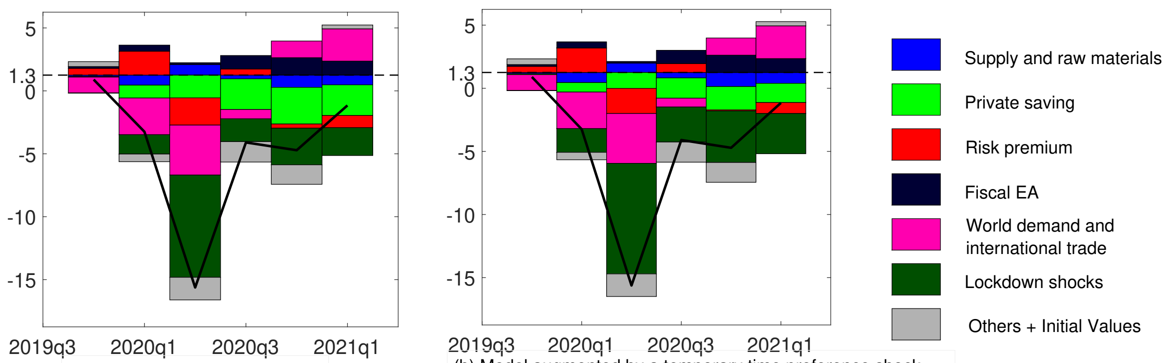
In this subsection we add time preference shocks, ε_t^{TB}, in line with Chen et al. (2020):[20]

$$\beta_t \equiv \beta^t \exp\left(\sum_{\tau=0}^{t-1}\left(\varepsilon_\tau^C + \varepsilon_\tau^{TB}\right)\right) \qquad \varepsilon_\tau^{TB} \sim MA(1)$$

that have a 1st-order moving average form, i.e. MA(1). The ε_t^{TB} shock is also part to the time preference shocks subject to habit persistence. The MA(1) specification implies a carry over of present innovations into the near future, i.e. current innovations affect shock

[20]The calibration of the shock process is reported in Table 4.

terms one quarter ahead, but not longer (contrary to the longer-lasting impact embedded in AR(1) processes). We next augment our baseline model with this specification and let the Kalman filter "decide", which shocks better explain the data during the COVID pandemic.



(a) Baseline model

(b) Model augmented by a temporary time preference shock

Figure 13: EA GDP growth decomposition across model variants (per cent, year-on-year)

Notes: The two panels show shock decomposition of real GDP growth in the EA (year-on-year) in (a) the benchmark model and (b) a model version augmented with a MA(1) time preference shock. The transitory forced saving and the MA(1) time preference shock are part of the 'lockdown shocks', whereas the two AR(1) time preference shocks form the group of 'private saving' shocks. See Figure 6 for additional details on the shock grouping.

In Figure (13), the transitory forced saving and the MA(1) time preference shocks are part of the group of 'lockdown shocks' (together with the labour hoarding shock), whereas the two AR(1) time preference shocks ('savings trend' and 'cyclical savings') form the group of 'private saving' shocks. Figure (13) shows that the introduction of the MA(1) time preference shock reduces the contribution of the 'private saving' shocks in the second half of 2020 compared to the benchmark model to the benefit of a stronger role for the group of lockdown shocks, which includes the MA(1) shock. The MA(1) specification introduces persistence in the lockdown shocks, which reduces the need for standard persistent 'private savings' shocks to capture the persistent COVID effects in the second half of 2020 and early 2021. The transitory forced saving shock remains the dominant factor in the group of lockdown shocks, however. It notably better explains the first wave of the COVID crisis, as shown in panel (b) of Figure (14), whereas the MA(1) time preference shock becomes more important during the 2nd and 3rd waves in late 2020 and early 2021, which have been associated with more entrenched restrictions on economic activity and where a continuation of restrictions could be expected weeks or months in advance given the epidemiological dynamics.

In Figure (15), we compare the benchmark model (panel a) to a version in which the

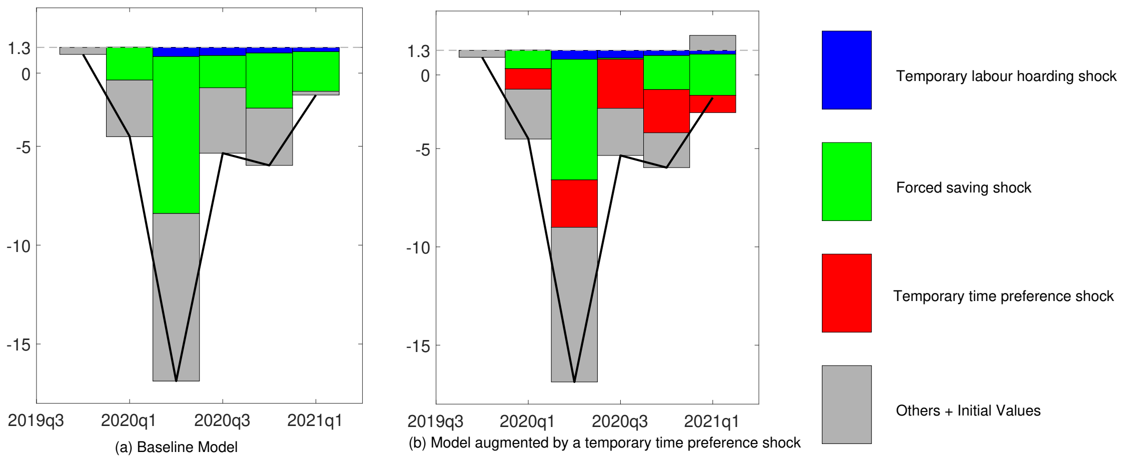
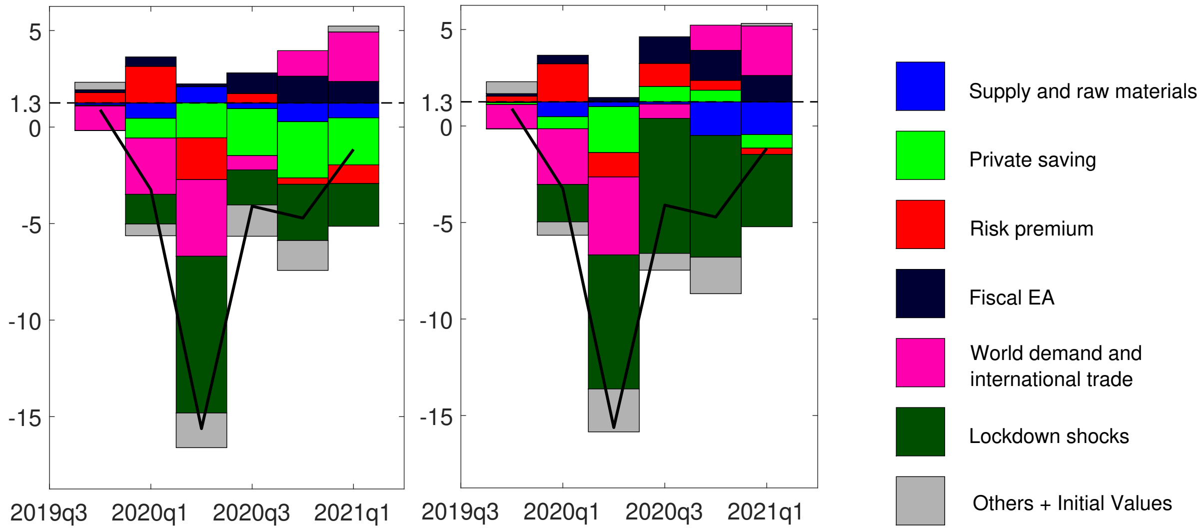


Figure 14: Individual lockdown shocks in the EA GDP growth decomposition

Notes: The chart expands the group of lockdown shocks from Figure 13, where panel (a) relates to the benchmark model and (b) to the variant with additional temporary time preference shock. The displayed categories are: (1) temporary labour hoarding shock (blue); (2) forced saving shock (light green); (3) temporary time preference shock (red);

transitory forced saving shock is removed and the MA(1) time preference shock the only consumption shock to proxy for the lockdown and social distancing during the COVID crisis in the 'lockdown' group (panel b). Removing the transitory forced savings shock ε_t^{tC} dampens the (negative) contribution of 'lockdown shocks' to GDP growth in 2020q2 (absence of the transitory shock that could account for the exceptional decline in activity in 2020q2). The contribution of lockdown shocks increases in 2020q3-q4 in panel (b) in light of the larger MA(1) shock (compared to panel a), while the private saving shocks almost vanish in response. The implied profile of lockdown shocks would differ strongly from the mobility and stringency indicators shown in Figure (10) above, however.

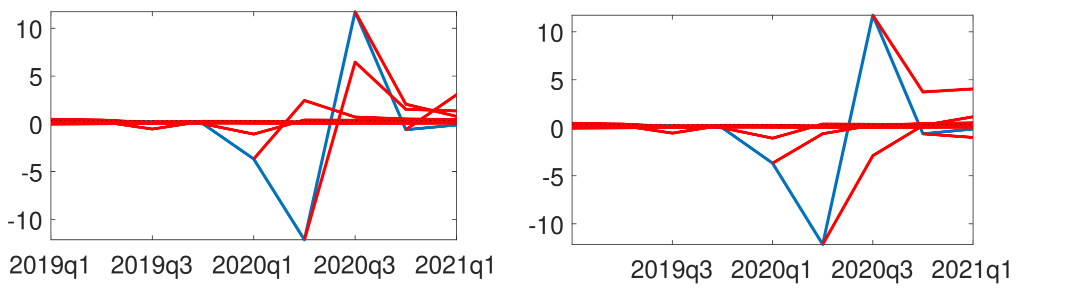
Comparing prediction accuracy, finally, provides information about the forecast performance of the two shock specifications, i.e. transitory forced saving versus MA(1) time preference shock, which affects the respective weight that model estimation attributes to them. Figure (16) shows the model-implied (unconditional) one-year-ahead projection for EA GDP growth at different points in time (red lines) in comparison to the observed growth rate (blue lines). The model variants in panels (a) and (b) correspond to (a) and (b) in Figure (15), respectively. The projections suggest that the transitory forced saving shock in panel (a) better replicates the V-shape of (quarterly) real GDP growth around the first wave of the COVID pandemic than the temporary time preference shock in panel



(a) Baseline model (b) Model with a temporary time preference shock

Figure 15: EA GDP growth decomposition without forced saving shock (per cent, year-on-year)

Notes: The two panels show shock decomposition of EA GDP growth (year-on-year) in (a) the benchmark model and (b) a model with temporary time preference but without forced saving shocks.



(a) Baseline model (b) Model with temporary time preference shock

Figure 16: EA GDP growth pseudo real-time forecasts

Notes: The two panels show recursive forecasts for EA real GDP growth in (a) the benchmark model and (b) a version with temporary MA(1) discount factor shock but without transitory forced savings shock. The blue lines show the observed quarter-on-quarter GDP growth rate. The red lines show the model-implied (unconditional) one-year-ahead prediction for subsequent quarters. The model is estimated until 2019q4, i.e. no repeated re-estimation up to the latest available data point in the projection exercise ('pseudo real-time forecast').

(b) that would imply excessively persistent growth surprises.

9 Conclusion

This paper uses an estimated two-region (EA, RoW) DSGE model to analyse the COVID-19 recession in the EA. In particular, we augment the European Commission's Global Multi-country (GM) model (Albonico et al. (2019); Kollmann et al. (2016); Giovannini et al. (2019)) with shocks and channels that have been of particular relevance during the COVID crisis. These elements include transitory 'forced saving' and labour hoarding shocks, which capture the impact of temporary lockdown measures or social distancing on demand and supply and the gap between employment and hours worked (short-time work), and firm liquidity constraints that link investment demand to firm profits. Shock decompositions highlight the importance of lockdown shocks, in particular 'forced savings', as main drivers of GDP growth in 2020, not only during the contraction in the first half, but also its partial recovery in the second half of the year. 'Forced savings' are transitory, contrary to the persistent standard saving shock that appears to become more important in the second half of 2020 and can be linked to precautionary motives (amidst uncertainty about the recovery and medium- and long-term implications of the pandemic) as well as entrenched restrictions. The estimated profile of the forced saving shock co-moves with empirical indicators of the stringency of restrictions and indicators of mobility. Our model suggests a rapid recovery as far as transitory 'lockdown shocks' are concerned. The prerequisite is an end of the health emergency, which allows lifting restrictions on economic activity. Where precautionary motives are important, the recovery may require more clarity on medium- and longer-term perspectives.

The global nature of the COVID-19 crisis has furthermore contributed to the recession through the decline in world demand and trade. Discretionary fiscal policy has had a stabilising impact on EA GDP in 2020. This includes short-term work schemes that have enabled comparatively stable employment and household income despite a sharp decline in actual hours worked. Fiscal multipliers are modest in light of the predominance of transfers to households, however. Instead of fostering aggregate demand by government spending, stabilisation policy has focused on income support and maintaining the productive infrastructure of the economy to contain negative spillover to non-confined sectors, limit scars and facilitate the subsequent rebound.

We also compare the pandemic recession to the financial crisis of 2008-09. Looking at the quarterly GDP growth profile, the financial crisis recession was more persistent than the COVID one. In addition, the financial crisis recession was driven by a contraction of investment demand together with global demand and trade, with, contrary to 2020-21, a lesser role of consumption demand. Traditional monetary policy stabilised the EA economy in 2008-09, whereas the ZLB has been binding during the pandemic recession. Obviously, the comparison of the two episodes relates to the EA aggregate (only), and results for the COVID recession will have to be revisited as more recent, and potentially revised data become available.

To the best of our knowledge, we are among the first to describe the 'economic essence' of the pandemic in the EA in an estimated DSGE model. We have limited our analysis to the economic effects of the pandemic and the implemented containment measures, without incorporating a dynamic interaction between economic activity and the pandemic itself. An interesting literature combining epidemiological and macroeconomic modelling has evolved on the latter point (e.g., Eichenbaum et al. (2020)). It goes beyond the scope of our paper. The latter focuses on the short-term implications (business cycle) of COVID-19. Much more work is needed to understand and quantify the pandemic's medium- and long-term implications (structural change, hysteresis effects).

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A Model details

This appendix provides additional model details omitted in the main text. The model shares many standard elements with Albonico et al. (2019) and we refer also to the model description contained therein.

A.1 Households

There are two representative households indexed r. Savers maximize lifetime utility

$$\max_{C_{j,t},B^{\mathcal{Q}}_{j,t}} E_0 \sum_{t=0}^{\infty} (\beta_t)^t \left\{ \frac{(C^s_{j,t} - hC^s_{t-1})^{1-\theta}}{1-\theta} - \omega^N_t \frac{(N^s_{j,t})^{1+\theta^N}}{1+\theta^N} + \sum_{\mathcal{Q}} B^{\mathcal{Q}}_{j,t}(\varepsilon^{\mathcal{Q}}_t - \alpha^{\mathcal{Q}}) \right\}, \tag{A.1}$$

subject to a sequence of budget constraints

$$P^C_t C^s_{j,t} + B_{j,t+1} = W_t N^s_{j,t} + D_t + R^r_t B_{j,t} + T^s_{j,t}, \tag{A.2}$$

The portfolio $B_{j,t}$ consists of risk-free domestic bonds (rf), one internationally traded asset (bw), denoted in euro currency, and domestic firm shares (S). We also include government bonds (G) in the portfolio. We have omitted this asset in the main text due to its negligible estimated effects. Each asset has gross nominal return R^Q_t. Thus, $R^r_t B_{j,t} = \sum_{\mathcal{Q}} R^Q_t B^{\mathcal{Q}}_{j,t}$. The net of transfers and taxes is

$$T^s_{j,t} = TR^s_{j,t} - tax^s_{j,t} - \tau^N W_t N^s_{j,t} - \tau^C P^C_t C^s_{j,t}, \tag{A.3}$$

where $TR^s_{j,t}, tax^s_{j,t}$, τ^C and τ^N denote transfers, lump-sum taxes, the consumption (sales) tax and the labor tax rate, respectively.

Saver households are identical and make identical choices. The first order necessary conditions in a symmetric equilibrium are for $\mathcal{Q} \in \{rf, bw, S, G\}$:

$$1 = E_t \left[\Lambda^s_{t,t+1} \frac{R^{\mathcal{Q}}_t + \varepsilon^{\mathcal{Q}}_t - \alpha^{\mathcal{Q}}}{1 + \pi^{C,vat}_{t+1}} \right], \tag{A.4}$$

where $\alpha^{rf} = 0$, $\lambda^s_t = (C^s_t - h^s C^s_{t-1})^{-\theta}$, and $\Lambda^s_{t,t+1} = \beta_t \frac{\lambda^s_{t+1}}{\lambda^s_t}$.

Approximating the first-order condition for investment in foreign bonds gives a standard uncovered interest rate parity condition:

$$E_t \left[\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \right] i^W_t = i^{rf}_t + rprem^W_t, \tag{A.5}$$

where i^W_t and $rprem^W_t$ are the return and risk premium on the foreign bond, respectively.

The remaining households with population share $1 - \omega^s$ are liquidity-constrained (c). In each period, they consume their wage incomes and net transfers/taxes. Thus,

$$P^C_t C^c_{j,t} = W_t N^c_{j,t} + T^c_{j,t}. \tag{A.6}$$

Total consumption by EA households is

$$C_t = (1 - \omega^s)\, C_t^c + \omega^s C_t^s \tag{A.7}$$

and total EA labor supply

$$N_t = (1 - \omega^s)\, N_t^c + \omega^s N_t^s. \tag{A.8}$$

A.2 Wage setting

The labor market structure follows Albonico et al. (2019): Households are providing differentiated labor services $N_{j,t}$ in a monopolistically competitive market. A labor union bundles labor hours provided by both types of domestic households into a homogeneous labor service and resells it to intermediate good producing firms. We assume that Ricardian and liquidity-constrained households' hours are distributed proportionally to their respective population shares. Since both households face the same labor demand schedule, each household works the same number of hours as the average of the economy. It follows that the individual union's choice variable is a common nominal wage rate for both types of households. The union maximizes the discounted future stream of the weighted average of lifetime utility of its members with respect to the wage and subject to the weighted sum of their budget constraints, $C_{j,t}$.

$$\max_{W_{j,t}} U_{j,t} = \sum_{t=0}^{\infty} (\beta_t)^t U(C_{j,t}, N_{j,t}, \cdot) \tag{A.9}$$

subject to:

$$P_t^C C_{j,t}^s + \omega^s B_{j,t+1} + \Gamma_{jt}^W = W_{j,t} N_{j,t} + \omega^s (R_t^r B_{j,t} + D_t) + T_{j,t} \tag{A.10}$$

$$N_{j,t} = \left(\frac{W_{j,t}}{W_t}\right)^{-\sigma^n} N_t, \tag{A.11}$$

where $\Gamma_{j,t}^W = \frac{\gamma^w(\sigma^n - 1)}{2} W_t N_t \left(\pi_t^w - \pi^w - (1 - sfw)(\pi_{t-1}^{C,vat} - \bar{\pi})\right)^2$ is a quadratic wage adjustment cost that is born by the households and 1-sfw is the share of wage setters that index the growth rate of wages to the previous period inflation. σ^n is the inverse of the steady state gross wage markup. Additionally, we allow for a slow adjustment of real wages as in Blanchard and Galí (2007). The resulting wage equation is:

$$\left(\frac{U_{N,t}}{\lambda_t}\right)^{1-\gamma^{wr}} \left[\frac{(1-\tau^N) W_{t-1}}{P_{t-1}^{C,vat}}\right]^{\gamma^{wr}} = \frac{W_t}{P_t^{C,vat}} (1 - \tau^N) \mu_t^w, \tag{A.12}$$

where μ_t^w is the fluctuating gross wage markup:

$$\mu_t^w = \mu^w + \frac{\mu^w \gamma^w}{1 - \tau^N} \left[\frac{\partial \Gamma_t^w}{\partial W_t} - \beta_t E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{1}{\pi_{t+1}^{C,vat} + 1} \frac{\partial \Gamma_{t+1}^w}{\partial W_t} + \frac{1}{\gamma^w} \varepsilon_t^U\right].$$

$\mu^w = (\frac{\sigma^n}{1-\sigma^n})^{\gamma^{wr}-1}$ is the steady state markup, γ^{wr} and γ^w govern real and nominal rigidity, respectively. ε_t^U is a labor supply shock. $U_{N,t}$ is the derivative of the utility function with respect to labor. $P_t^{C,vat}$ is price of consumption goods adjusted for the sales tax ($P_t^{C,vat} = (1+\tau^C)P_t^C$).

A.3 Intermediate goods

Each firm $i \in [0,1]$ produces a variety of the domestic good which is an imperfect substitute for varieties produced by other firms. Firms are monopolistically competitive and face a downward-sloping demand function for goods.

Differentiated goods are produced using total capital, $K_{i,t-1}^{tot}$, and labor, $N_{i,t}$, which are combined in a Cobb-Douglas production function:

$$Y_{i,t} = \left(A_t^Y N_{i,t}\right)^{\alpha} \left(cu_{i,t} K_{i,t-1}^{tot}\right)^{1-\alpha} - A_t^Y \Phi_i, \tag{A.13}$$

where α is the steady-state labor share, A_t^Y represents the labor-augmenting productivity common to all firms in the differentiated goods sector, $cu_{i,t}$ denotes firm-specific capital utilization. Φ_i captures fixed costs in production. Total capital is a sum of private installed capital, $K_{i,t}$, and public capital, $K_{i,t}^G$:

$$K_{i,t}^{tot} = K_{i,t} + K_{i,t}^G. \tag{A.14}$$

Since total factor productivity (TFP) is not a stationary process, we allow for two types of technology shocks, ε_t^{GA} and ε_t^A. They are related to a non-stationary process and its autoregressive component ρ^A:

$$\log(A_t^Y) - \log(A_{t-1}^Y) = g_t^A + \varepsilon_t^A, \tag{A.15}$$

$$g_t^A = \rho^A g_{t-1}^A + (1-\rho^A) g^A + \varepsilon_t^{GA}, \tag{A.16}$$

where g_t^A and g^A are the time-varying growth and the long-run growth of technology, respectively.

Monopolistically competitive firms maximize the real value of the firm $\frac{P_t^S}{P_t} S_t^{tot}$, that is the discounted stream of expected future profits, subject to the output demand $Y_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{-\sigma^y} Y_t$, the technology constraint (A.13) and a capital accumulation equation $K_{i,t} = I_{i,t} + (1-\delta)K_{i,t-1}$.[21] Their problem can be written as:

$$\max_{P_{i,t}, N_{i,t}, I_{i,t}, cu_{i,t}, K_{i,t}} \sum_{s=t}^{\infty} D^S \Pi_{i,t}^f, \tag{A.17}$$

where the stochastic discount factor, D^S, is:

$$D^S = \frac{1+r_t^S}{\Pi_{r=t}^S (1+r_r^S)} \tag{A.18}$$

with $1 + r_t^S = \frac{1+i_{t+1}^S}{1+\pi_{t+1}}$ being the real stock return.

$P_{i,t}$ is the price of intermediate inputs and the corresponding price index is:

$$P_t = \left(\int_0^1 (P_{i,t})^{1-\sigma^y} di\right)^{\frac{1}{1-\sigma^y}}. \tag{A.19}$$

[21] We assume that the total number of shares $S_t^{tot} = 1$.

The period t profit of an intermediate goods firm i is given by:

$$\Pi^f_{i,t} = (1-\tau^K)\Big(\frac{P_{i,t}}{P_t}Y_{i,t} - \frac{W_t}{P_t}(N_{i,t}+\varepsilon^{tN}_t)\Big) + \tau^K\delta\frac{P^I_t}{P_t}K_{i,t-1} - \frac{P^I_t}{P_t}I_{i,t} - \Gamma_{i,t}, \tag{A.20}$$

where $I_{i,t}$ is the physical investment at price $P^I_{i,t}$, τ^K is the corporate tax and δ the capital depreciation rate.

Firms face quadratic factor adjustment costs, $\Gamma_{i,t}$, measured in terms of production input factors:

$$\Gamma_{i,t} = \Gamma^P_{i,t} + \Gamma^N_{i,t} + \Gamma^I_{i,t} + \Gamma^{cu}_{i,t} \tag{A.21}$$

Specifically, the adjustment costs are associated with the output price $P_{i,t}$, labor input $N_{i,t}$, investment $I_{i,t}$, as well as capacity utilization variation $cu_{i,t}$:

$$\Gamma^P_{i,t} = \sigma^y\frac{\gamma^P}{2}Y_t\left[\frac{P_{i,t}}{P_{i,t-1}} - \exp(\bar{\pi})\right]^2, \tag{A.22}$$

$$\Gamma^N_{i,t} = \frac{\gamma^N}{2}Y_t\left[\frac{N_{i,t}+\varepsilon^{tN}_t}{N_{i,t-1}+\varepsilon^{tN}_{t-1}} - \exp(g^{pop})\right]^2, \tag{A.23}$$

$$\Gamma^I_{i,t} = \frac{P^I_t}{P_t}\left[\frac{\gamma^{I,1}}{2}K_{t-1}\Big(\frac{I_{i,t}}{K_{t-1}} - \delta^K_t\Big)^2 + \frac{\gamma^{I,2}}{2}\frac{(I_{i,t} - I_{i,t-1}\exp(g^Y + g^{P^I}))^2}{K_{t-1}}\right], \tag{A.24}$$

$$\Gamma^{cu}_{i,t} = \frac{P^I_t}{P_t}K^{tot}_{i,t-1}\left[\gamma^{cu,1}(cu_{i,t}-1) + \frac{\gamma^{cu,2}}{2}(cu_{i,t}-1)^2\right], \tag{A.25}$$

where γ-parameters capture the degree of adjustment costs. $\bar{\pi}$ denotes steady state inflation. g^{pop}, g^Y, and g^{PI} are trend factors of population, GDP and prices for investment goods, respectively. $\delta^K_t \neq \delta$ is a function of the depreciation rate adjusted for the capital trend in order to have zero adjustment costs on the trend-path.[22]

Given the Lagrange multiplier associated with the technology constraint, μ^y, the FOCs with respect to labor, capital, investments and capital utilization are given by:

$$(1-\tau^K)\frac{W_t}{P_t} = \alpha\left(\mu^y_t - \varepsilon^{ND}_t\right)\frac{Y_t}{N_t} - \frac{\partial\Gamma^N_t}{\partial N_t} + E_t\Big[\frac{1+\pi_{t+1}}{1+i^s_{t+1}}\frac{\partial\Gamma^N_{t+1}}{\partial N_t}\Big], \tag{A.26}$$

$$Q_t = E_t\left[\frac{1+\pi_{t+1}}{1+i^s_{t+1}}\frac{P^I_{t+1}}{P_{t+1}}\frac{P_t}{P^I_t}\left(\tau^K\delta^K - \frac{\partial\Gamma^{cu}_t}{\partial K_{t-1}} + Q_{t+1}(1-\delta) + (1-\alpha)\mu^Y_{t+1}\frac{P_{t+1}}{P^I_{t+1}}\frac{Y_{kt+1}}{K^{tot}_t}\right)\right], \tag{A.27}$$

$$\frac{I_t}{K_{t-1}} - \delta^K_t = sli_t\Big(\zeta_1\left(\frac{GOS_{i,t}}{K_{i,t-1}}\frac{P_t}{P^I_t}\right) - \zeta_0 - \delta^K\Big) + \frac{1-sli_t}{\gamma^{I,1}}Q_t - 1 - \gamma^{I,2}\frac{(I_t - I_{t-1}\exp(g^Y+g^{P^I}))}{K_{t-1}}$$
$$+E_t\Big[\frac{1+\pi_{t+1}}{1+i^s_{t+1}}\frac{P^I_{t+1}}{P_{t+1}}\frac{P_t}{P^I_t}\exp(g^Y+g^{P^I})\gamma^{I,2}\frac{(I_{t+1} - I_t\exp(g^Y+g^{P^I}))}{K_t}\Big], \tag{A.28}$$

[22] We specify $\delta^K_t = exp(g^Y + g^{PI}) - (1-\delta)$ so that $\frac{I}{K} - \delta^k \neq 0$ along the trend path.

$$\mu_t^y (1-\alpha)\frac{Y_t}{cu_t}\frac{P_t}{P_t^I} = K_{t-1}^{tot}\Big[\gamma^{u,1} + \gamma^{u,2}(cu_t - 1)\Big], \tag{A.29}$$

where $Q_t = \mu_t^y / \frac{P_t^I}{P_t}$.

In a symmetric equilibrium ($P_{i,t} = P_t$), the FOC with respect to $P_{i,t}$ yields the New Keynesian Phillips curve:

$$\begin{aligned}\mu_t^y \sigma^y = (1-\tau^K)(\sigma^y - 1) + \sigma^y \gamma^P \frac{P_t}{P_{t-1}}\Big(\pi_t - \bar{\pi}\Big) \\ - \sigma^y \gamma^P \left[\frac{1+\pi_{t+1}}{1+i_{t+1}^s}\frac{P_{t+1}}{P_t}\frac{Y_{t+1}}{Y_t}\Big(\pi_{t+1} - \bar{\pi}\Big)\right] + \sigma^y \varepsilon_t^\mu,\end{aligned} \tag{A.30}$$

where here ε_t^μ is a white noise markup shock. The final New Keynesian Phillips curve takes then the following form:

$$\begin{aligned}\mu_t^y \sigma^y &= (1-\tau^K)(\sigma^y - 1) + \sigma^y \gamma^P \frac{P_t}{P_{t-1}}\Big(\pi_t - \bar{\pi}\Big) \\ &- \sigma^y \gamma^P \frac{1+\pi_{t+1}}{1+i_{t+1}^s}\frac{P_{t+1}}{P_t}\frac{Y_{t+1}}{Y_t}\left[sfp\Big(\pi_{t+1} - \bar{\pi}\Big) + (1-sfp)(\pi_{t-1} - \bar{\pi})\right] \\ &+ \sigma^y \varepsilon_t^\mu,\end{aligned} \tag{A.31}$$

where sfp is the share of forward looking price setters.

A.4 Fiscal policy

The government collects taxes on labor, τ^N, capital, τ^K, consumption, τ^C, and lump-sum taxes, tax_t, and issues one-period bonds, B_t^G, to finance government consumption, G_t, investment, I_t^G, transfers, T_t, and the servicing of the outstanding debt. The tax on commodity imports from RoW, τ^{IS}, is fixed. The government budget constraint is:

$$B_t^G = (1 + i_{t-1}^G)B_{t-1}^G - R_t^G + P_t^G G_t + P_t^{IG} I_t^G + T_t P_t, \tag{A.32}$$

where nominal government revenues, R^G, are defined as:

$$\begin{aligned}R_t^G = \tau^K(P_t Y_t - W_t N_t - P_t^I \delta K_{t-1}) + \tau^N W_t N_t + \tau^C P_t^C C_t \\ + \tau^{IS} P_t^{Y0} IS_t + tax_t P_t Y_t.\end{aligned} \tag{A.33}$$

The government closes its budget via lump sum taxes:

$$tax_t = \rho^\tau tax_{t-1} + \eta^d \left(\frac{\Delta B_{t-1}^G}{Y_{t-1}P_{t-1}} - \bar{def}\right) + \eta^B \left(\frac{B_{t-1}^G}{Y_{t-1}P_{t-1}} - \bar{BG}\right) + \varepsilon_t^{tax}, \tag{A.34}$$

where $\bar{def}$ and $\bar{BG}$ are the targets on government deficit and government debt with debt rule coefficients η^d and η^B, respectively. ε_t^{tax} is a white noise shock. ρ^τ governs the debt rule persistence.

The accumulation equation for government capital is:

$$K_t^G = (1-\delta)K_{t-1}^G + I_t^G, \tag{A.35}$$

where δ is the depreciation rate.

The model uses a measure of discretionary fiscal effort (DFE) as defined by the European Commission (2013):

$$DFE_t = \frac{R_t^G}{Y_t^N} - \frac{\Delta E_t^G - (\frac{y_t^{pot}}{y_{t-1}^{pot}} - 1)E_{t-1}^G}{Y_t}, \tag{A.36}$$

where R_t^G stands for government revenues in nominal terms, E_t^G is the adjusted nominal expenditure aggregate, y_t^{pot} is the medium-term nominal potential output, and Y_t^N is nominal GDP.[23] Following the definition of DFE, we define the aggregate nominal expenditure as:

$$E_t^G = P_t^G G_t + P_t^{IG} I_t^G + P_t T_t. \tag{A.37}$$

We use the following discretionary fiscal effort rules for government consumption, G_t, investment, I_t^G, and transfers, T_t:

$$\frac{G_t P_t^G - G_{t-1}P_{t-1}^G}{P_t Y_t} = \left(\frac{Y_t^{pot}}{Y_{t-1}^{pot}}\exp(\pi_t) - 1\right)\frac{G_{t-1}P_{t-1}^G}{P_t Y_t} - \alpha_t^G\left(\frac{G_{t-1}P_{t-1}^G}{P_{t-1}Y_{t-1}} - \bar{G}\right) + \varepsilon_t^G, \tag{A.38}$$

$$\frac{I_t^G P_t^{IG} - I_{t-1}^G P_{t-1}^{IG}}{P_t Y_t} = \left(\frac{Y_t^{pot}}{Y_{t-1}^{pot}}\exp(\pi_t) - 1\right)\frac{I_{t-1}^G P_{t-1}^{IG}}{P_t Y_t} - \alpha_t^{IG}\left(\frac{I_{t-1}^G P_{t-1}^{IG}}{P_{t-1}Y_{t-1}} - \bar{I}^G\right) + \varepsilon_t^{IG}, \tag{A.39}$$

$$\frac{T_t P_t - T_{t-1}P_{t-1}}{P_t Y_t} = \left(\frac{Y_t^{pot}}{Y_{t-1}^{pot}}\exp(\pi_t) - 1\right)\frac{T_{t-1}P_{t-1}}{P_t Y_t} - \alpha_t^T\left(\frac{T_{t-1}P_{t-1}}{P_{t-1}Y_{t-1}} - \bar{T}\right) + \varepsilon_t^T, \tag{A.40}$$

where ε_t^G, ε_t^{IG}, ε_t^T are shocks to government consumption, investment and transfers, respectively. The policy feedback parameters $\alpha_t^G, \alpha_t^{IG}$, $\alpha_t^T > 0$ ensure long-run stability of the model.

A.5 RoW details

RoW Phillips curve. The intermediate good producers use labor to manufacture domestic goods (non-oil output) according to a linear production function.

$$Y_t^* = A_t^{Y,*} N_t^* \tag{A.41}$$

where $A_t^{Y,*}$ captures a trend in the productivity and $N_t^* = Actr_t^* Pop_t^*$ is the active population in the economy.

Price setting for non-oil output follows a New Keynesian Phillips curve:

$$\pi_t^{Y,*} - \bar{\pi}^{Y,*} = \beta_t^* \frac{\lambda_{t+1}^*}{\lambda_t^*}\left[sfp^*(\pi_{t+1}^{Y,*} - \bar{\pi}^{Y,*}) + (1-sfp^*)(\pi_{t-1}^* - \bar{\pi}^*)\right] + \phi^{y,*}\log\frac{Y_t^*}{\bar{Y}^*} + \varepsilon_t^{Y,*}, \tag{A.42}$$

where $\lambda_t^* = (C_t^* - h^* C_{t-1}^*)^{-\theta^*}$ is the marginal utility of consumption, $\varepsilon_t^{Y,*}$ is a cost push shock, sfp^* is the share of forward looking price setters.

[23] The adjusted nominal expenditure removes interest payments and non-discretionary unemployment expenditures from total nominal expenditure.

Commodities. The price of the commodity bundle is

$$P_t^{IS,*} = \varepsilon_t^{P^{IS}} \left[(1 - s^{ec})(P_t^{nec,*})^{1-\sigma^{IS}} + s^{ec}(P_t^{ec,*})^{1-\sigma^{IS}} \right]^{\frac{1}{1-\sigma^{IS}}}, \tag{A.43}$$

with substitution elasticity σ^{IS}, share parameter s^{ec}, and EA-specific commodity price shock $\varepsilon_t^{P^{IS}}$.

Euler equation. RoW households maximize utility (27) subject to the aggregate budget constraint

$$P_t^* Y_t^* + D_t^* = P_t^{C,*} C_t^* + TB_t^*, \tag{A.44}$$

where D_t^* are dividends from intermediate good producers, and TB_t^* are net exports. The consumption Euler equation is

$$1 = E_t \left[\Lambda_{t,t+1}^* \frac{R_t^*}{1 + \pi_{t+1}^{C,*}} \right], \tag{A.45}$$

where $\Lambda_{t,t+1}^* = \beta \exp(\varepsilon_t^{C,*}) \frac{(C_{t+1}^* - h^* C_t^*)^{-\theta^*}}{(C_t^* - h^* C_{t-1}^*)^{-\theta^*}}$.

B Data, calibration, and posterior estimates

B.1 Data sources

The analysis uses quarterly and annual data for the period 1999q1 to 2021q1 based on the data set of the European Commission's Global Multi-country Model (Albonico et al., 2019). This appendix repeats the description contained therein for convenience. Data for EMU countries and the Euro Area aggregate (EA19) are taken from Eurostat (in particular, from the European System of National Account ESA95). Bilateral trade flows are based on trade shares from the GTAP trade matrices for trade in goods and services. The Rest of the World (RoW) data are annual data and are constructed using IMF International Financial Statistics (IFS) and World Economic Outlook (WEO) databases.

Series for GDP and prices in the RoW start in 1999 and are constructed on the basis of data for the following 58 countries: Albania, Algeria, Argentina, Armenia, Australia, Azerbaijan, Belarus, Brazil, Bulgaria, Canada, Chile, China, Colombia, Croatia, Czech Republic, Denmark, Egypt, Georgia, Hong Kong, Hungary, Iceland, India, Indonesia, Iran, Israel, Japan, Jordan, Korea, Lebanon, Libya, FYR Macedonia, Malaysia, Mexico, Moldova, Montenegro, Morocco, New Zealand, Nigeria, Norway, Philippines, Poland, Romania, Russia, Saudi Arabia, Serbia, Singapore, South Africa, Sweden, Switzerland, Syria, Taiwan, Thailand, Tunisia, Turkey, Ukraine, United Arab Emirates, United Kingdom, USA and Venezuela. When not available, quarterly-frequency data are obtained by interpolating annual data using the TRAMO-SEATS package developed by Gómez and Maravall (1996).

Table 2 lists the observed time series. GDP deflators and relative prices of aggregates are computed as the ratios of current price value to chained indexed volume. The trend component of total factor productivity is computed using the DMM package developed by Fiorentini et al. (2012). The obtained series at quarterly frequency is then used to estimate potential output.

We make a few transformations to the raw investment series. In particular, we compute the deflator of public investments based on annual data and then obtain its quarterly frequency counterpart through interpolation. This series together with nominal public investments is then used to compute real quarterly public investments. In order to assure consistency between nominal GDP and the sum of the nominal components of aggregate demand, we impute change in inventories to the series of investments.

Euro Area	
i	Nominal short term interest rate
$\log(actr_k)$	Log of active rate population
$\log \frac{B^g}{Y}$	Log of nominal gov. bonds share
$\log \frac{C^g}{Y}$	Log of nominal gov. consumption share
$\log \frac{C}{Y}$	Log of nominal consumption share
$\log(e)$	Log effective nominal exchange rate
$\log \frac{i^g}{Y}$	Log of nominal gov. interest payments share
$\log \frac{I^g}{Y}$	Log of nominal gov. investment share
$\log \frac{I}{Y}$	Log of nominal investment share
$\log \frac{M}{Y}$	Log of nominal total import share
$\log(N)$	Log of hours
$\log \frac{P^{c,vat}}{P}$	Log of consumption price final to observed GDP price
$\log \frac{P^g}{P}$	Log of gov. observed price to observed GDP price
$\log \frac{P^{IG}}{P}$	Log of govt. investment price to observed GDP price
$\log \frac{P^I}{P}$	Log of observed total investment price to observed GDP price
$\log \frac{P^M}{P}$	Log of import price to observed GDP price
$\log(Pop)$	Log of population
$\log \frac{P^X}{P}$	Log of export price to GDP price
$\log(P)$	Log of observed GDP price
$\log(t\bar{f}p)$	Log of TFP trend
$\log \frac{T}{Y}$	Log of nominal gov transfers share
$\log \frac{W}{Y}$	Nominal wage share
$\log \frac{X}{Y}$	Log of nominal export share
$\log(Y)$	Log of observed GDP
$\frac{IS}{Y}$	Nominal industrial supply import share
P^{IS}	Price of industrial supply
$\log \frac{TB}{Y}$	Nominal trade balance share
Rest of the World	
i^*	RoW nominal Interest rate
P^{ec}	Oil price
$\log(Pop)$	Log of population
$\log(P)$	Log of observed GDP price
$\log(Y)$	Log of observed GDP
$\log(\bar{Y})$	Log of GDP trend

Table 2: List of observables.

B.2 Calibration and posterior estimates

Table 3 reports the calibrated parameter values.

Monetary Policy		
Nominal interest rate in SS	$\bar{i}$	0.004
CPI inflation in SS	$\bar{\phi}^{c,vat}$	0.005
Interest rate persistence	ρ^{i}	0.919
Response to inflation	$\eta^{i,\phi}$	2.282
Response to output gap	$\eta^{i,y}$	0.108
Households		
Preference for government bonds	α^{B}	-0.002
Preference for stocks	α^{S}	0.004
Preference for foreign bonds	α^{BW}	0.010
Intertemporal discount factor	β	0.998
Savers share	ω^{S}	0.670
Import share in consumption	$s^{M,C}$	0.097
Import share in investment (private and gov)	$s^{M,I}$	0.148
Import share in exports	$s^{M,X}$	0.138
Weight of disutility of labor	ω^{N}	3.627
Steady state markup	μ^{W}	1.200
Production		
Cobb-Douglas labor share	α	0.650
Depreciation of private capital stock	δ	0.014
Share of oil in total output	s^{Oil}	0.037
Linear capacity utilization adj. costs	$\gamma^{u.1}$	0.028
Value-added demand elasticity	σ^{y}	8.014
Fiscal policy		
Consumption tax	τ^{C}	0.200
Corporate profit tax	τ^{k}	0.300
Labor tax	τ^{N}	0.437
Deficit target	def^{T}	0.025
Debt target	$\bar{BG}$	3.104
Steady state ratios		
Private consumption share in SS	C/Y	0.557
Private investment share in SS	I/Y	0.183
Govt consumption share in SS	C^{G}/Y	0.205
Govt investment share in SS	I^{G}/Y	0.031
Transfers share in SS	T/Y	0.165
Monetary Policy RoW		
Interest rate persistence	ρ^{i*}	0.905
Response to inflation	$\eta^{i,\phi*}$	1.820
Response to output gap	$\eta^{i,y*}$	0.254
COVID related shocks		
Forced saving shock	ε^{tC}	0.04
Labour hoarding shock	ε^{tN}	0.005

Table 3: Selected calibrated parameters.

Calibrated parameters							
Temporary time preference (std)	ε_t^{TB}				0.02		
Temporary time preference (MA(1) coeff.)	ρ^{TB}				0.5		
Estimated parameters							
		Prior distribution			Posterior distribution		
		Distr.	Mean	Std.	Mode	10%	90%
Forced saving - std.	ε^{TUC}	Gamma	0.01000	0.0025	0.00108	0.00112	0.00134

Table 4: Parameters used for robustness check.

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