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The impact of COVID-19 confinement in the Euro Area: a Bayesian DSGE approach

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Abstract

With the aim of providing a preliminary forecast of the economic repercussion of the recent confinement, we estimate a canonical medium-scale dynamic stochastic general equilibrium model (DSGE) for the Euro Area economy, augmented with financial frictions. Relying on such characterisation of the economy, we carry out a series of simulations in which we use a shock to the labour supply as the primary conductor of the consequences of this pandemic disturbance. Moreover, we assess the adequacy of quantitative easing policies that many central banks are adopting as a measure to counterbalance the economic damage caused by COVID-19. We conclude that these initiatives serve as an immediate response, but they are limited by central banks' inflation target and should be accompanied by other measures able to speed up the recovery in the medium and long run.

Keywords: DSGE model, Euro Area, COVID-19, recession, monetary policy, quantitative easing.

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1 Introduction

Unfortunately, 2020 will go down in history as the year of COVID-19 pandemic and social distancing due to confinement. The first case was documented at the end of 2019 in Wuhan, China (Liu, Kuo, and Shih, 2020). By the middle of February, while the rest of the world was still astonished with the strict measures that the Chinese government was imposing, the virus had already spread to many other countries, including six in the Euro Area (Spiteri et al., 2020). On March 9th and March 14th Italy and Spain, respectively, confined their population, followed by most of their partners in the common market. Such a large-scale stop in our normal activity has consequences that are still far from certain. In the following lines we try to shed some light on this topic, with focus on the economic impact of confinement in the Euro Area. For this purpose we will estimate a medium-scale dynamic stochastic general equilibrium (DSGE) model, following mainly the approach in Smets and Wouters (2007).

As pointed out by Becker, Hege, and Mella-Barral (2020), the coronavirus crisis has come in times of a private sector considerably indebted, which had showed little improvements since the financial crisis of 2007-2008. The authors highlight that the policies adopted will "inevitably leave parts of the corporate sector with even larger debt burdens" and therefore "delay a recovery" (p. 37). Consequently, we augment the model by implementing an endogenous financial sector to account for the important role that firms' debt may have. In particular, we consider the state-of-the-art model designed by Gelain and Ilbas (2017), which incorporates financial rigidities *à la* Gertler and Karadi (2011) in the DSGE model from Smets and Wouters (2007).

Some authors integrate a sanitary sector in macroeconomic models, allowing to explore the consequences of different policies not only on economic variables but also on the number of contagions and deceased. Such modelling is beyond the scope of this work, since our aim is to approximate the consequences of policies actually adopted rather than contrasting which would have been the effects of other alternatives. However, there are interesting contributions in that line of investigation. It is worthy to mention Kaplan, Moll, and Violante (2020), in which the authors assemble an Heterogeneous-Agent New Keynesian (HANK) model with an epidemiological SIR model. This combination reveals some degree of trade-off between protecting more lives and minimising the economic damage. This idea is also supported by Eichenbaum, Rebelo, and Trabandt (2020). At last, they provide an interesting, yet preliminary, analysis of different policies seeking for describing the frontier of possibilities in this trade-off.

Initially, we estimate the model by Bayesian methods, making use of Dynare (Matlab) and with data for the Euro Area until the last quarter of 2019. Once we have the estimated values of the model parameter that characterise the Euro Area, we proceed with a series of simulations, focusing on a labour supply shock as the main conductor of COVID-19 confinement consequences. It may be seen as a strong simplification, given that confinement has probably generated disturbances of other natures. Remarkably, a demand shock associated to consumption and investment (Wren-Lewis, 2020). Eichenbaum et al. (2020) asserts that "these effects [from supply and demand sides] work in tandem to generate a large, persistent recession". However, according to Rio-Chanona, Mealy, Pichler, Lafond, and Farmer's (2020) comparison, the largest shocks would come from the supply side. Furthermore, Guerrieri, Lorenzoni, Straub, and Werning (2020) show that demand deficiencies can originate in reductions in labour supply, like the ones we emulate with the shock that we have chosen. They give the name of "Keynesian supply shocks" to those supply shocks whose impact on aggregate demand is larger than the shock itself. One of the requirements for this event to take place is that the fall in employment only affects some sectors. Other facilitators of this disturbance shift are incomplete markets, liquidity constrained consumers and low substitutability across sectors. Fornaro and Wolf (2020) elaborate more on this idea talking about a doom loop between supply and demand disturbances. Goodhart and Pradhan (2020) also place labour supply as the main cause of the macroeconomic effects of the pandemic. Finally, we find strong support for our approach in Mihailov (2020). This author considers the model developed by Galí, Smets, and Wouters (2012), relatively close to the one used in this analysis, and models the pandemic disruption as a labour supply shock.

During the simulations, we assume different potential scenarios by varying the persistence and magnitude of the shock. But in every case we calibrate its impact in a way that the simulated variables match the preliminary data already available for the first quarter of 2020. Once these simulations are calibrated to match the observed data, they serve as forecasts of how the relevant variables will behave in the following quarters. Our results are robust and point to a relatively fast recovery in terms of growth rates. However, the absence of a marked bounce-back effect implies that the convergence to the steady state will be slow. In other words, our findings suggest a long-standing process of recovery for the levels of the variables, given that the recession will not be followed by a period of high growth rates. Our conclusions should nonetheless be taken cautiously, in light of the limitations of the preliminary data at our reach.

Finally, we assess the efficiency of a policy of quantitative easing, like many central banks are adopting, as a possible strategy to speed up the economic recovery. We find that, indeed, it mitigates the effects of the lock-down, at the cost of an increase in prices. Therefore, the dramatic economic fall that we have experienced cannot be counterbalanced only with quantitative easing measures, because the rise in inflation would exceed the limit set by the European Central Bank. Hence, these initiatives can be considered for a short-term neutralization of the recession, but they should be accompanied by additional measures with focus on the medium and long run.

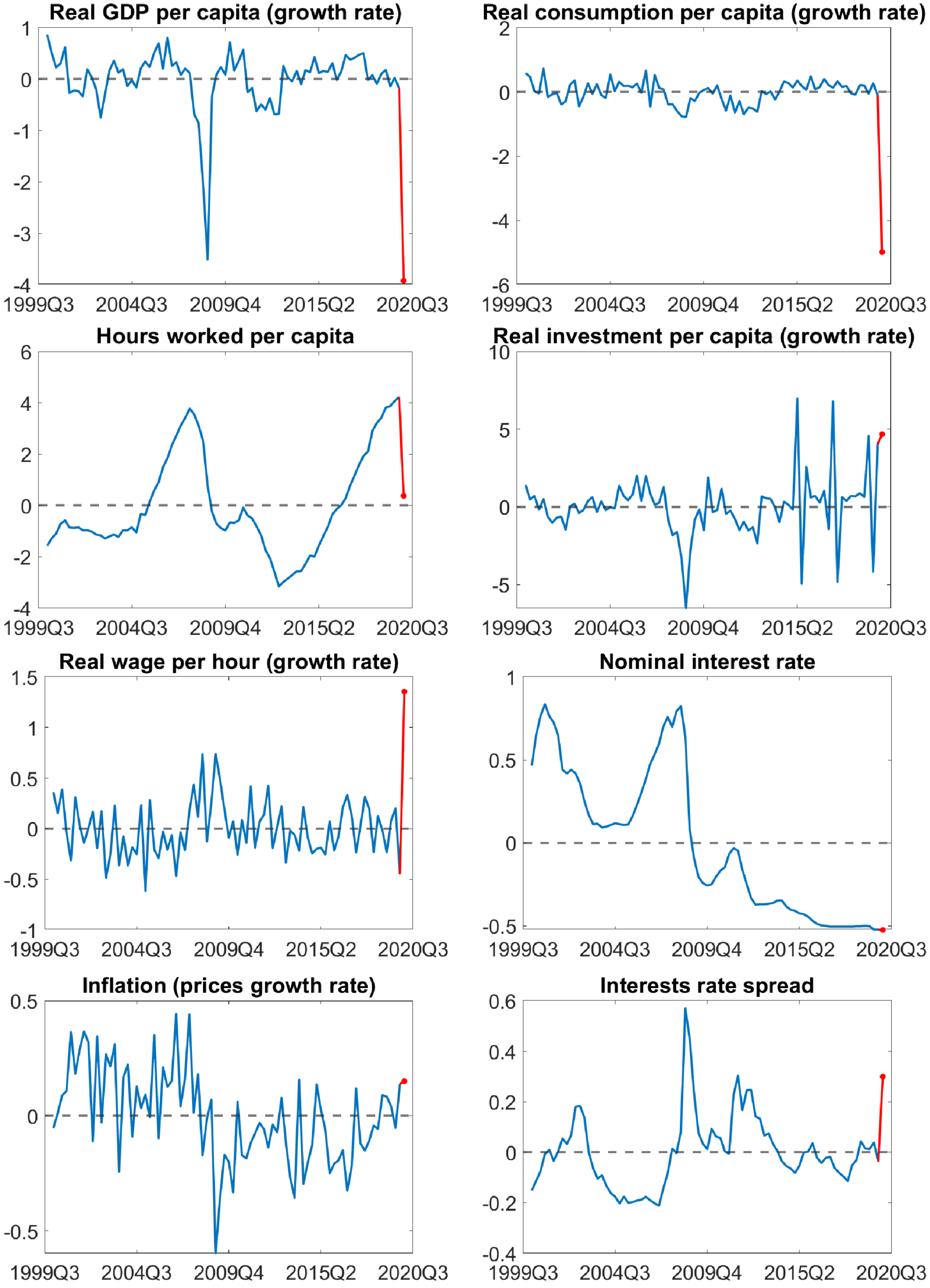
This paper is structured as follows. In Section 2 we discuss the nature of the pandemic shock that we are confronting. Section 3 provides a description of the model. Section 4 presents the results of the estimation. Section 5 exposes the findings of the simulation exercise that we carry out in order to approximate the economic effects of the lock-down. Section 6 includes additional simulations in which we incorporate the quantitative easing programme to the model. Lastly, Section 7 offers some concluding remarks.

2 Calibrating the pandemic shock

Figure 1 shows the evolution of some relevant variables in the Euro Area since the beginning of the new millennium and until the first quarter of 2020, in which the pandemic shock comes into play. It should be noted that there may be deeper consequences not captured by traditional data, since their computations were not designed to capture the effects of a lock-down. For instance, education has continued remotely but its costs have remained unchanged, thus not having impact on its GDP contribution. Nevertheless, it is unlikely that the services offered have been the same. Moreover, the observed data for this first quarter of the year are preliminary and will be revised in the following months. Even so, they still should offer a notion of how the economy is responding.

Figure 1

Observed series (2000Q1 - 2020Q1)



Notes. Real variables are expressed as first differences of logarithms. Hours worked in logarithms. Interest rate and spread in levels. All series are measured in deviations from their sample means. The first period of the confinement (2020Q1) is marked in red.

The lock-down has caused dramatic falls in employment and production, similarly as the previous crisis. Consumption, which also drops, makes a notorious difference. We had not seen such sudden stop in the last decades. In contrast, investment has augmented, although at a lower scale. Furthermore, even though the aggregate salaries have diminished, the impact has been much softer than on the total hours worked, leading to a considerable increase in real wages per hour. Oblivious to the unpredictability of the situation, inflation and nominal interest rates remain relatively stable. In the financial sector, the abrupt take-off in the risk premium reveals the sudden outbreak of uncertainty.

Most countries in the Euro Area have followed similar measures to face the tragedy. People has been forced to stay at home for their own safety. The duration has varied across state members, but four months after the beginning of lock-downs, restrictions have only been relaxed, not lifted yet. As a consequence, labour force has been largely lessened, although the impact has been unequal for different economic sectors. And still if they had not imposed any measures, authorities' decisions might have had limited effects, as highlighted by Moser and Yared (2020). Even without governmental enforcement, people on their own initiative would reduce consumption and labour (Baker, Farrokhnia, Meyer, Pagel, and Yannelis, 2020). These voluntary decisions, in spite of contributing to get the pandemic under control, have a harmful impact on the economy (Eichenbaum et al., 2020).

As unexpected as it has been, COVID-19 is not devoid of precedents. Jordà, Singh, and Taylor (2020) make an extensive analysis of past pandemics from the last six centuries. This work discloses a historical growth in real wages and lower real natural rate during the three or four decades after pandemics.[1] But their main finding is that, unlike wars, pandemics are historically followed by periods with low returns to assets and scarce investment opportunities. The authors point to the excess of capital for a decimated population and higher reservations to put wealth into risk as the most likely explanations. This condition might be especially intense this time, due to the unequal impact of COVID-19. The nature of the virus makes it affect more severely the elderly, who tend to save more in relative terms. According to Oswald and Powdthavee (2020), age is the determinant factor for fatality of the disease. The greater acuteness on elderly could explain that countries with low-quality health system but younger population present lower mortality rates than developed countries, with their advanced sanitary services but considerably older citizens, on average.

3 The model

In our desire to find a proper characterisation of the Euro Area economy, we will estimate a DSGE model as the one used in Smets and Wouters (2007) to study the sources of business cycle fluctuations in the United States. In addition, we introduce a financial sector to control for rigidities in funding, following Gertler and Karadi (2011) and Gelain and Ilbas (2017). In this section we describe briefly the model. Nonetheless, a more detailed explanation can be found in the references previously listed.

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[1] As defined in Jordà et al. (2020), "the real natural rate of interest is the level of real returns on safe assets which equilibrates an economy's savings supply and investment demand" (p. 4) without altering prices.

3.1 Final goods producers

Inspired in Kimball (1995), Smets and Wouters (2007) consider a composite final good. Firms in this sector buy intermediate goods and combine them, to create the final product that they supply to customers, investors and the government. As any other firms, they seek to maximise their profits. On the one hand, their earnings come from sales of this composite good, Y_t, at a price P_t. On the other hand, in this process of assembly they need intermediate goods, which are paid at different prices, $P_t(i)$ for each good i.

$$\max_{\{Y_t, Y_t(i)\}} \; P_t Y_t - \int_0^1 P_t(i) Y_t(i) di.$$

In this problem their range of decision is limited by the following constraint:

$$\left[\int_0^1 G\left(\frac{Y_t(i)}{Y_t}; \varepsilon_t^p\right) di\right] = 1,$$

where G is a strictly concave and increasing function such that $G(1) = 1$. As defined in Kimball (1995), it is an aggregator, which decomposes the final good into the combination of a variety of inputs. The restriction implies that there are no spillovers in the production process, but also that firms in this sector do not enlarge output, just re-package it. Hence, it takes one unit of intermediate production to make a unit of retail output. The model also includes a price mark-up disturbance, ε_t^p, to introduce changes in the elasticity of demand of intermediate goods and, as a consequence, in the mark-up.

3.2 Intermediate goods producers

In this sector, intermediate goods are produced and sold to final good firms. In their production process they employ capital and labour. An intermediate firm i produces accordingly to the following technology:

$$Y_t(i) = \varepsilon_t^a \left(K_t^s(i)\right)^{\alpha} \left(\gamma^t L_t(i)\right)^{1-\alpha} - \gamma^t \Phi,$$

where Φ is a fixed cost of production and γ^t is the labour-augmenting deterministic growth rate of the economy. The shock in this function, ε_t^a, represents the total factor productivity.

Firms want to maximise profits, which are given by the difference between the monetary value of output and the amounts set aside for hiring the production inputs.

$$\max_{\{K_t^s(i), L_t(i)\}} \; \Pi_t = P_t(i) Y_t(i) - W_t L_t(i) - R_t^k K_t^s(i).$$

The model adopts Calvo's (1983) pricing scheme with partial indexation. At every period, a fraction ξ_p of firms is allowed to adjust their prices. Meanwhile, the rest of companies can only update theirs in accordance with an indexation rule to adapt to variations in prices. In this framework, a company allowed to re-optimise its price will make its decision taking into account not only the present but also all the forthcoming periods in which it will not be permitted to adjust again. Thus, the optimisation problem they confront is:

$$\max_{\{\tilde{P}_t(i)\}} \; E_t \sum_{s=0}^{\infty} \xi_p^s \frac{\beta^s \Xi_{t+s} P_t}{\Xi_t P_{t+s}} \left[\tilde{P}_t(i) \left(\prod_{l=1}^{s} \pi_{t+l-1}^{\iota_p} \pi_*^{1-\iota_p}\right) - MC_{t+s}\right] Y_{t+s}(i),$$

$$s.t. \; Y_{t+s}(i) = Y_{t+s} G'^{-1}\left(\frac{P_t(i) X_{t,s}}{P_{t+s}} \tau_{t+s}\right),$$

where $\tilde{P}_t(i)$ is the newly set price, π_t is inflation, $\frac{\beta^s \Xi_{t+s} P_t}{\Xi_t P_{t+s}}$ is the stochastic discount rate, $\tau_t = \int_0^1 G'\left(\frac{Y_t(i)}{Y_t}\right)\frac{Y_t(i)}{Y_t}di$ and

$$X_{t,s} = \begin{cases} 1 & for\ s = 0 \\ \left(\prod_{l=1}^{s} \pi_{t+l-1}^{\iota_p} \pi_*^{1-\iota_p}\right) & for\ s = 1, ..., \infty \end{cases}$$

3.3 Households

Household j consumes $C_t(j)$ and acquire bonds $B_t(j)$. They also supply labour, $L_t(j)$, for which they receive a compensation $W_t(j)$. Their other sources of funding are bonds previously acquired, payouts $Div_t(j)$ from ownership of firms and transfers $T_t(j)$ from the government. Their decisions are affected by the inertia of previous decisions through λ, which represents external habit formation.

Households' preferences are modelled with a non-separable utility function which depends on two factors: consumption of goods and time worked. Families want to maximise the sum of this flow of utilities weighted by a discount factor and considering an infinite life horizon:

$$\max_{\{C_t(j), B_t(j), L_t(j)\}} E_t \sum_{s=0}^{\infty} \beta^s \left[\frac{1}{1-\sigma_c}(C_{t+s}(j) - \lambda C_{t+s-1})^{1-\sigma_c}\right] exp\left(\frac{\sigma_c - 1}{1+\sigma_l}\varepsilon_t^l L_{t+s}(j)^{1+\sigma_l}\right).$$

This objective function only differs from Smets and Wouters (2007) in that we incorporate a shock to labour supply, ε_t^l. The impulse-response functions shown in Smets and Wouters (2003) make us think that this type of disturbance can be especially suitable to explain the effects that we are observing in these tumultuous times.

Families decision is restricted by their budget constraint:

$$C_{t+s}(j) + \frac{B_{t+s}(j)}{\varepsilon_t^b R_{t+s} P_{t+s}} - T_{t+s} = \frac{B_{t+s-1}(j)}{P_{t+s}} + \frac{W_{t+s}^h(j) L_{t+s}(j)}{P_{t+s}} + \frac{Div_{t+s}(j)}{P_{t+s}},$$

where ε_t^b is an exogenous premium on riskier rates over the risk-free rate set by the central bank, or a premium required by households to hold the bond.

Families are composed by workers and bankers. There is some degree of mobility from one sector to the other, but the fraction of each type is fixed. A household's member can enter banking thanks to the dividends obtained from ownership of firms.

3.4 Financial intermediaries

Below we provide a brief explanation of how financial frictions are implemented. We follow Gertler and Karadi (2011), in which a more detailed description can be found. This sector consists of bankers acting as financial intermediaries, who borrow funds from households and lend them to non-financial firms. Their balance sheet is as follows:

$$Q_t S_{j,t} = N_{j,t} + B_{j,t+1},$$

where $N_{j,t}$ is the net worth of the banker j at the end of the period, $B_{j,t+1}$ are the deposits borrowed from households, and $S_{j,t}$ is the amount of claims on non-financial firms that the intermediary holds, whose relative price is given by Q_t.

The activity is profitable for intermediaries because they obtain from holding their assets higher rates than they pay to the depositaries. This difference, which is called risk premium, gives room to the formation of bankers' equity capital. The law of motion of net worth is:

$$N_{j,t+1} = R_{k,t+1}Q_tS_{j,t} - R_{t+1}B_{j,t+1} = (R_{k,t+1} - R_{t+1})Q_tS_{j,t} + R_{t+1}N_{j,t}.$$

The risk premium is given by $R_{k,t+1} - R_{t+1}$. As long as it is positive, the banker will benefit from channelling more funds between savers and borrowers.

Let $(1-\theta)$ be the probability that a banker will exit the industry and $\beta^i \frac{U^c_{t+i}}{U^c_t}$ the stochastic discount that the intermediary applies to earnings at period $t+i$, being U^c_t the marginal utility of consumption at period t. Therefore, a banker aiming at maximising the expected terminal wealth will face the following problem:

$$\begin{aligned}\max_{\{S_{j,t+i}\}} V_{j,t} &= E_t \sum_{i=0}^{\infty} (1-\theta)\theta^i \beta^{i+1} \frac{U^c_{t+i+1}}{U^c_t} N_{j,t+i+1} = \\ &= E_t \sum_{i=0}^{\infty} (1-\theta)\theta^i \beta^{i+1} \frac{U^c_{t+i+1}}{U^c_t} \left[(R_{k,t+i+1} - R_{t+i+1})Q_tS_{j,t+i} + R_{t+i+1}N_{j,t+i}\right].\end{aligned}$$

To limit the ability of bankers to expand their assets indefinitely by borrowing funds from households, Gertler and Karadi (2011) introduce a moral hazard/costly enforcement problem: intermediaries can divert a fraction Γ_t of available funds to their own households. Despite the fact that they assume this fraction is constant, we will take it as time-varying, as initially suggested by Bean, Paustian, Peñalver, and Taylor (2010) or Dedola, Karadi, and Lombardo (2013). More precisely, we will take Gelain and Ilbas' (2017) approach and model it as an exogenous AR(1) process. Thus, it can be interpreted as a financial shock which reflects variations in how large depositors judge the probability of bankers diverting resources. Hence, households supply funds on the condition that intermediary's potential loss due to diversion exceeds the expected gains:

$$\Gamma_t Q_t S_{j,t} \leq V_{j,t}.$$

When this constraint binds, the total amount of assets that the intermediaries can achieve depends on their equity capital: $Q_tS_t = \phi_t N_{j,t}$, being ϕ_t the ratio of assets to equity, also known as intermediaries' leverage. Then, the evolution of net worth can be expressed as:

$$N_{j,t+1} = \left[(R_{k,t+1} - R_{t+1})\phi_t + R_{t+1}\right] N_{j,t}.$$

Finally, the law of motion for N_t lies in the sum of the net worth of old and new bankers, respectively $N_{e,t}$ and $N_{n,t}$.

$$N_t = N_{e,t} + N_{n,t} + N_* \varepsilon^{nw}_t.$$

We extend the initial model by introducing ε^{nw}_t, an exogenous shock to the net worth, which will let us have a closer monitoring of the actual behaviour of this variable. N_* is the total net worth at the steady state. Additionally, note that the net worth of veteran intermediaries corresponds to the capital equity of those bankers from the previous period that did not change sector.

$$N_{e,t} = \theta\left[(R_{k,t} - R_t)\phi_{t-1} + R_t\right] N_{t-1}.$$

3.5 Capital goods producers

This sector consists of competitive capital producing firms. They repair capital acquired from intermediate goods producing firms and also build new capital. Afterwards, both are sold to capital services firms. We assume that the cost of substituting deteriorated capital with new is unity and that the value of a new capital unit is Q_t. Furthermore, adjustment costs for refurbishing capital are not considered. However, the model does suppose that there are flow adjustment costs when new capital is built. Profits go to households, as they hold capital producers.

Capital firms want to maximise their profits. Denoting gross capital created by I_t, net capital created by $I_{n,t}$ such that $I_{n,t} \equiv I_t - \delta(U_t)\xi_t K_t$ and I_{ss} the steady state investment, the problem to optimise is:

$$\max_{\{I_{n,\tau}\}} E_t \sum_{\tau=t}^{\infty} \beta^{T-\tau} \frac{U^c_{t+i}}{U^c_t} \left[(Q_\tau - 1) I_{n,\tau} - f\left(\frac{I_{n,\tau} + I_{ss}}{I_{n,\tau-1} + I_{ss}} \right) (I_{n,\tau} + I_{ss}) \right],$$

where $f(1) = f'(1) = 0$, $f''(1) > 0$, and $\delta(U_t)\xi_t K_t$ is the quantity of capital refurbished.

The stock of capital evolves according to the law of capital accumulation:

$$K_t(j) = (1-\delta)K_{t-1}(j) + \varepsilon^i_t \left[1 - S\left(\frac{I_t(j)}{I_{t-1}(j)} \right) \right] I_t(j),$$

where δ is the depreciation rate and ε^i_t is an exogenous shock to investment relative to consumption goods. Adjustment costs are assumed to be quadratic. They are defined by the function $S({}^{I_t}/{}_{I_{t-1}})$, which is a strictly increasing twice differentiable function. It satisfies the properties $S(1) = S'(1) = 0$, and $S''(1) > 0$.

3.6 Capital services firms

Firms in this sector purchase the capital goods offered by capital goods producers. Capital services firms decide the utilisation rate (Z_t), which determines the amount of effective capital available for renting:

$$K^s_t = Z_t K_{t-1}.$$

Therefore, the income from renting equals $R^k_t Z_t K_{t-1}$. They can vary the level of capital employed, but the change implies some adjustment costs: $a(Z_t)K_{t-1}$. Then, the maximisation problem for companies in this sector is:

$$\max_{\{Z_t\}} \left[R^k_t Z_t - a(Z_t) \right] K_{t-1}.$$

Capital services firms borrow from financial intermediaries in order to finance their physical capital acquisition. And given that each claim is priced the same as a unit of capital, then at equilibrium:

$$Q_t K_{t+1} = Q_t S_t.$$

3.7 Labour unions and labour packers

In order to introduce rigidities in wages under a Calvo scheme, the model sets up a framework with two intermediaries between labour supply and labour demand. Initially, households are suppliers of homogeneous labour. It is acquired by a labour union, which differentiates it. At this stage, intermediate packers use this differentiated labour to create a package, L_t, to supply intermediate goods producers.

Labour packers achieve profits from the discrepancy between what intermediate producers pay for their labour packages and what unions charge for differentiated labour. There is, therefore, a gap between W_t, the wage rate earned by the packer, and $W_t(i)$, the wage rate of intermediate labour services.

$$\max_{\{L_t, L_t(i)\}} W_t L_t - \int_0^1 W_t(i) L_t(i) di.$$

They face a resources constraint, just like the one in final goods producers' problem. In this case, the restriction implies that the intermediate packers supply exactly the same units of labour they hire from unions:

$$\left[\int_0^1 H\left(\frac{L_t(i)}{L_t}; \varepsilon_t^w\right) di\right] = 1,$$

being H is a Kimball aggregator, like the one in the final goods production function, and ε_t^w a shock that affects the wage mark-up through the elasticity of demand.

At the previous stage, labour unions decide wages à la Calvo with partial indexation. They can re-optimise wages with probability ξ_w. Therefore, those allowed set a wage rate $\tilde{W}_t(i)$ that optimises not only current but also future earnings, taking into account the probability not to be able to change salaries again in some time. Analogously to labour packer's case, the profits for the union come from the difference between what they earn for the heterogeneous labour they supply and what they pay to the homogeneous workers they employ.

$$\max_{\{\tilde{W}_t(i)\}} E_t \sum_{s=0}^{\infty} \xi_w^s \frac{\beta^s \Xi_{t+s} P_t}{\Xi_t P_{t+s}} \left[\tilde{W}_t(i) \left(\prod_{l=1}^{s} \gamma \pi_{t+l-1}^{\iota_w} \pi_*^{1-\iota_w} - W_{t+s}^h\right)\right] L_{t+s}(i).$$

Additionally, they are subject to a demand constraint that comes from the optimal solution to labour's packer problem.

$$L_{t+s}(i) = L_{t+s} H'^{\,-1} \left[\frac{W_t(i) X_{t,s}^w}{W_{t+s}} \int_0^1 H'\left(\frac{L_t(i)}{L_t}\right) \frac{L_t(i)}{L_t} di\right].$$

3.8 Government and central bank

The central bank follows a Taylor rule, under which it is committed to control inflation and output gap. Furthermore, the economic growth, understood as variations in the output gap, is also regulated. Formally,

$$\frac{R_t}{R^*} = \left(\frac{R_{t-1}}{R^*}\right)^{\rho} \left[\left(\frac{\pi_t}{\pi_*}\right)^{r_\pi} \left(\frac{Y_t}{Y_t^*}\right)^{r_y}\right]^{1-\rho} \left(\frac{Y_t/Y_{t-1}}{Y_t^*/Y_{t-1}^*}\right)^{r_{\Delta y}} \varepsilon_t^r,$$

where R^* and Y_t^* are, respectively, the steady state nominal rate and natural output. ρ is a parameter that determines the degree of interest rate smoothing. Finally, a shock to monetary policy, ε_t^r is incorporated.

Regarding the government, it is financed by lump-sum taxes and bonds. These economic resources are destined to the repayment of previously issued bonds and government spending. In terms relative to the steady state output path, government spending $\varepsilon_t^g = \frac{G_t}{Y\gamma^t}$ is modelled as another exogenous shock. This disturbance also collects the net-exports effects on aggregate demand, which are ignored in this closed-economy model. Consequently, it can react to developments in productivity, that affect competitiveness in external markets.

3.9 Resource constraint

Finally, the whole economy is restricted by the availability of limited resources. Therefore, the production has to be divided between private consumption and investment, government's expenditure and capital adjustment costs.

$$C_t + I_t + G_t + a(Z_t)K_{t-1} = Y_t.$$

3.10 Exogenous disturbances

The economy presented above is subject to the influence of ten different perturbations. Seven of them (ε_t^a, ε_t^l, ε_t^b, ε_t^i, Γ_t, ε_t^{nw} and ε_t^r) follow AR(1) processes. Mark-ups on prices and wages, ε_t^p and ε_t^w, are described by ARMA(1,1) processes. Finally, exogenous spending, ε_t^g, follows an AR(1), augmented with a component that interacts with the productivity shock. A more detailed explanation for each disturbance is provided in Appendix II.

4 Estimation

At equilibrium, all the agents solve their maximisation problems and all markets clear. Therefore, the first order conditions derived from each sector hold. We log-linearise these equations to introduce them in Dynare. They can be consulted in Appendix I.

In our search for the best characterisation of the economy, we do not want to simply calibrate the model to start our simulations at the observed values of the variables one period before the coronavirus outbreak. Instead of that, we estimate the model with data for the 20 previous years. More precisely, we use quarterly data for the Euro Area in the period 2000Q1 - 2019Q4. After the estimation, the model itself is able to bring the economy to the starting point for the simulations, 2019Q4. Our main data source is Eurostat. Appendix III provides more information about the time series employed.

For the macroeconomic building block of the model, we use a set of variables for the Euro Area which is equivalent to the one used in Smets and Wouters (2007) for the US. All real variables are divided between the working age population, to have them in per capita terms. They are also multiplied by 1000 due to the difference of scale: real variables are measured in million euro whereas population comes in thousand people. The nominal wage is divided between the GDP deflator and the labour force, to obtain real wage per hour worked. And, for the same reason as real variables, we multiply it by 1000. Finally, the interest rate is divided by 4 to adapt it to quarterly return and by 100 because it comes as a percentage. In this way, we get our set of macroeconomic observables, consisting of real GDP per capita, real consumption per capita, real investment per capita, real wage per hour worked, nominal interest rate, hours worked per capita and the GDP deflator.

As we are implementing a financial extension of the model, we include additional financial series. In particular, we opted for credit spread, as a proxy for the risk premium.[2] Gelain and Ilbas (2017) use Gilchrist and Zakrajšek's (2012) spread. However, this measure is constructed for the US. In consequence, we take the version for the Euro

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[2] Gilchrist and Zakrajšek (2012) shows that credit spread is closely related to financial intermediary balance and therefore is an adequate proxy for the risk premium.

Area from Gilchrist and Mojon (2018), which follows the same methodology.[3] This decision to use the spread seems especially appropriate considering the great proportion of corporate debt that is currently rated at the lowest investment grade rating (Becker et al., 2020).

Finally, we have to take logarithms of the data. Only the interest rate and the spread remain unchanged. As we are dealing with a relatively small sample period, we demean all the observables instead of estimating their steady state growth path. The historical value that is subtracted from each variable is shown in Table 1. Additionally, variables in logarithms are multiplied by 100, to have them in percentage terms.

Table 1

Estimated historical values

Variable	$dy = \ln\left(\frac{Y_t}{Y_{t-1}}\right)$	$dc = \ln\left(\frac{C_t}{C_{t-1}}\right)$	$dinve = \ln\left(\frac{I_t}{I_{t-1}}\right)$	$pinf = \ln\left(\frac{P_t}{P_{t-1}}\right)$
Average	0.0029	0.0023	0.0029	0.0039

Variable	$dw = \ln\left(\frac{W_t}{W_{t-1}}\right)$	$lab = \ln L_t$	r	$Prem$
Average	0.0022	5.6262	0.4218	0.3403

We use Bayesian methods for the estimation through Dynare, in Matlab.[4] For lack of identifiability, some parameters need to be fixed in advance, as in Smets and Wouters (2007), and in Gelain and Ilbas (2017). More precisely, the quarterly depreciation rate, δ; the wage mark-up at the steady state, ϕ_w; the share of exogenous spending in total production, g_y; the curvature of the Kimball aggregator in both goods and labour markts, ε_p and ε_w; the proportion of transfers to new bankers, ω; the steady state return to capital, $\overline{crk}$; the common trend growth for the real variables, $\overline{\gamma}$; households' discount factor, β; the steady state level of the net premium, $\overline{cs}$, and the net worth growth at the steady state, $\overline{cn}$. Table 2 contains the values chosen, which are retrieved from the calibrations and prior assumptions suggested in the related literature.

Table 2

Fixed parameters

δ	ϕ_w	g_y	ε_p	ε_w	ω	$\overline{crk}$	$\overline{\gamma}$	β	$\overline{cs}$	$\overline{cn}$
0.025	1.5	0.18	10	10	0.002	1.29	0.4	0.9975	0.48	2.27

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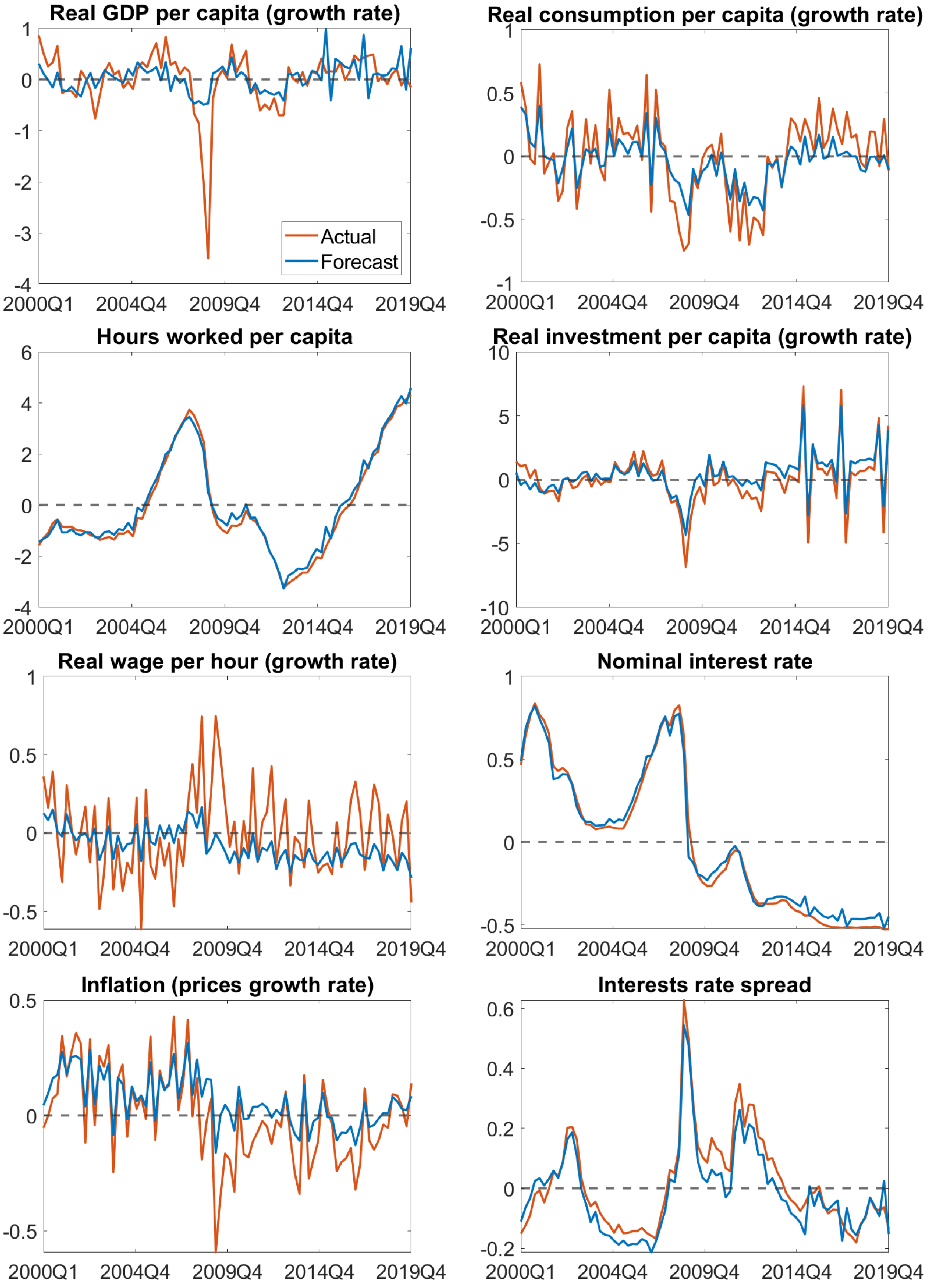
[3] The time series can be downloaded from https://publications.banque-france.fr/en/economic-and-financial-publications-working-papers/credit-risk-euro-area

[4] There is an extensive literature addressing Bayesian estimation of DSGE models. See, for instance, Fernández-Villaverde (2010) and Guerrón-Quintana and Nason (2013) to get a clear and deep understanding of this estimation technique.

Figure 2

Actual vs 1-step ahead forecast series



The estimation procedure provides standard values for the parameters, broadly in line with those reported in Smets and Wouters (2003) for the Euro Area and by Smets and Wouters (2007) for the US. These estimates turn out to be quite robust, even when the model is modified in some way. Thus, the values obtained are similar when accounting for financial rigidities (Gelain and Ilbas, 2017), for adaptive learning (Slobodyan and Wouters, 2012; Aguilar and Vázquez, 2019), or for news shocks (Herrera and Vázquez, 2020). Tables 3 and 4 in Appendix IV show the parameter estimates. Moreover, Figure 2 indicates that the Bayesian estimation procedure presents a good fit between the actual series and the forecasts made one quarter in advance, even if it smooths their high frequency fluctuations. Therefore, in light of the evidence, we conclude that the estimated model offers a sound characterisation of the economy in the Euro Area.

5 Simulations

Approximating the reality through the estimation of a DSGE model is not a main goal of this work, but rather a means to tackle the macroeconomic consequences induced by the shock that confinement has meant. We address such aim by simulating the five years after the coronavirus outbreak. Hence, the first period simulated is the first quarter of 2020, which is generated from the levels and trends of the variables until 2019Q4 that we have estimated in the previous section, but also taking into account the intense economic disruption that the pandemic has entailed. As previously announced, we use the labour supply shock as the primary exogenous variable in this exercise. In other words, we assume that the pandemic shock hits the economy in a similar way as a disturbance to the labour supply, but of a much greater magnitude this time.

We set up our baseline case by assuming that the persistence of this disturbance is the one estimated for the labour supply shock, $\rho_l = 0.991$. Arguably, the lock-down is a very atypical situation which need not be represented by the labour shock estimated in our model before the pandemic, but it certainly helps as a reference. Moreover, we carry out a robustness analysis by repeating this exercise for different values of persistence. We obtain two remarkable outcomes. Interestingly, this value of persistence is the one making the simulation fit best the data observed in 2020Q1. Besides, the most relevant findings regarding the duration of the recession turn out to be quite robust.[5] Furthermore, we have solid reasons to expect this labour supply disturbance to be highly persistent. First, many adaptations implemented during the lock-down are likely to stay. For instance, remotely working (Willcocks, 2020), the re-thinking of supply chains (Donthu and Gustafsson, 2020) and, in general, the new organisational structures derived from the confinement restrictions. Second, in a world considerably interconnected, the economic consequences in regions being hit by the disease will propagate to other areas, even if they have already overcome the health crisis (Inoue and Todo, 2020). Third, individuals, firms and the entire society have changed. Our consumption patterns will probably take a long time before getting back to normal, if they do (Sheth, 2020). Fourth, these effects can be exacerbated by people's current negative expectations regarding the recovery (Codagnone et al., 2020). Finally, the mere threat of new outbreaks disrupts the economy (Chen, Qian, and Wen, 2020).

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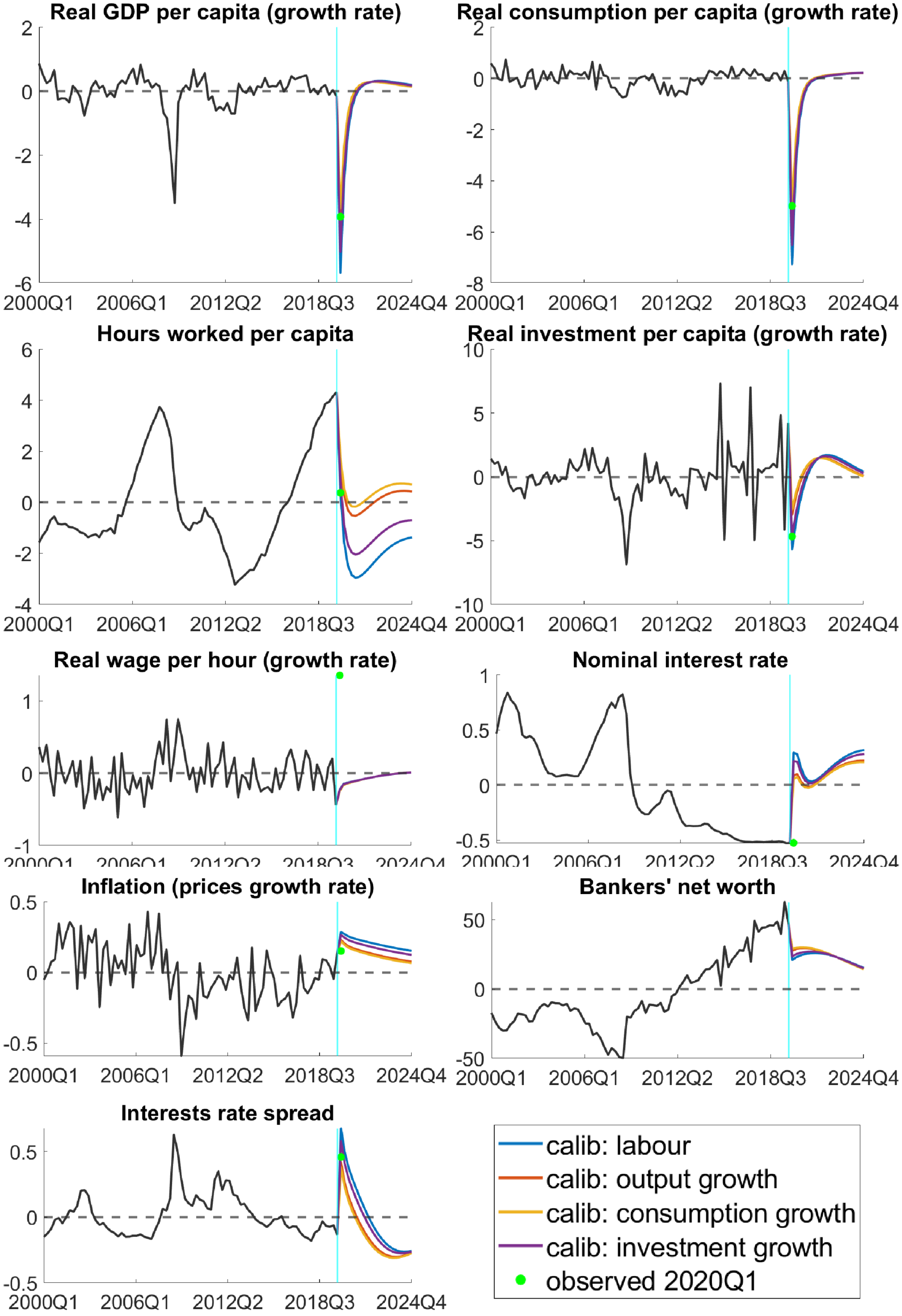
[5] We consider the following values for the persistence of the shock: 0.95, 0.90, 0.85 and 0.75, but the recovery of growth rates is not substantially accelerated or delayed in any of these cases. Values of persistence under 0.75 result in considerable variations in the reactions of some variables, up to the point of not being consistent with the 2020Q1 observed data available. The impulse-response functions for a persistence value of 0.90 can be found in Appendix V.

Figure 3

Simulation results $(\rho_l = 0.991)$



We consider four possible calibrations for the magnitude of the shock, in a way that either the hours worked, the output growth, the consumption growth or the investment growth simulated roughly matches the actual observation for the first quarter of 2020. The graphs in Figure 3 show the results of the simulations under these four scenarios. Given that they only differ in the assumptions regarding the pandemic shock, they overlap until 2019Q4, when the disease hit our society. Moreover, even after the disruption we observe that the four paths imply similar patterns for most of the relevant variables. Remarkably, the simulations replicate fairly well the preliminary data for the first observation of the year, which is represented by a green point. Only prices escape to our approximation. Simulated inflation is slightly over the actual value. This is likely due to the fact that the economy has been subject to strong deflationary pressures since the Great Recession. In the case of the nominal interest rate, the model predicts how it should respond to these stimuli under normal circumstances, but it is not able to seize the actual monetary policy due to the zero lower bound. With respect to the compensations of employees, the simulation gets right the sign of the response, but underestimates its magnitude. A possible reason for this finding is that the model does not account for the heterogeneous impact of the shock across different economic sectors.

While this analysis illustrates the impact of a pandemic shock, the impulse-response functions (IRF) are more suitable for the analysis of the dynamics after the shock. They show the reaction of the economy to an external event along a specified time horizon, compared to the steady state situation. Hence, we have to interpret them as a measure of the deviations that the shock causes, with respect to how the economy was expected to behave at the steady state. In this case, we focus on a horizon of five years since the worldwide spread of the disease.

Figure 4 contains the IRFs for the pandemic shock, *i.e.* a highly persistent shock to the supply of labour. They show the simulated behaviour of the variables in the forthcoming years. Notice the square-root-shaped recovery forecasted for the growth rate of real production and real consumption. They start with a huge fall and then, at the beginning of next year, they grow again at steady state rates. The IRFs quickly become flat. Investment, which follows a similar path, suffers the largest reduction. A plausible explanation is provided by Farmer and Gabriel (2020): "as the COVID-19 crisis places even greater strain on the economy and on public finances, it will be tempting to view greater investment in innovation as a luxury, to be abandoned in favour of addressing more immediate concerns" (p. 37). The recovery is also slower but it shows the most pronounced bounce-back effect. In 2022 it reaches growth rates over the steady state, and therefore speeds up the recovery of pre-crisis levels. Labour is substantially affected and does not start to recover in levels until next year. Concerning real wages, our model does not predict great variations, as previously discussed. Therefore, it does not capture the striking increase seen in the first quarter of 2020. We have to wait until more information is available in order to know whether it was a momentary event due to the initial and stricter measures of confinement or it will persist. The increase in nominal interest rates forecasted by our model is well over the actual observation. It goes against the long-run decrease in interest rates after pandemics noticed by Jordà et al. (2020). The zero lower bound of the Taylor rule that we considered is probably the cause. Besides, we come from times with unusually low rates, what may have been important in this case. Regarding inflation, the model predicts a modest and long-lasting increase. In the financial sector, we observe that bankers will be severely affected for around two years, and that the risk premium will still take some time to be controlled.

Figure 4

Impulse-Response functions ($\rho_l = 0.991$)

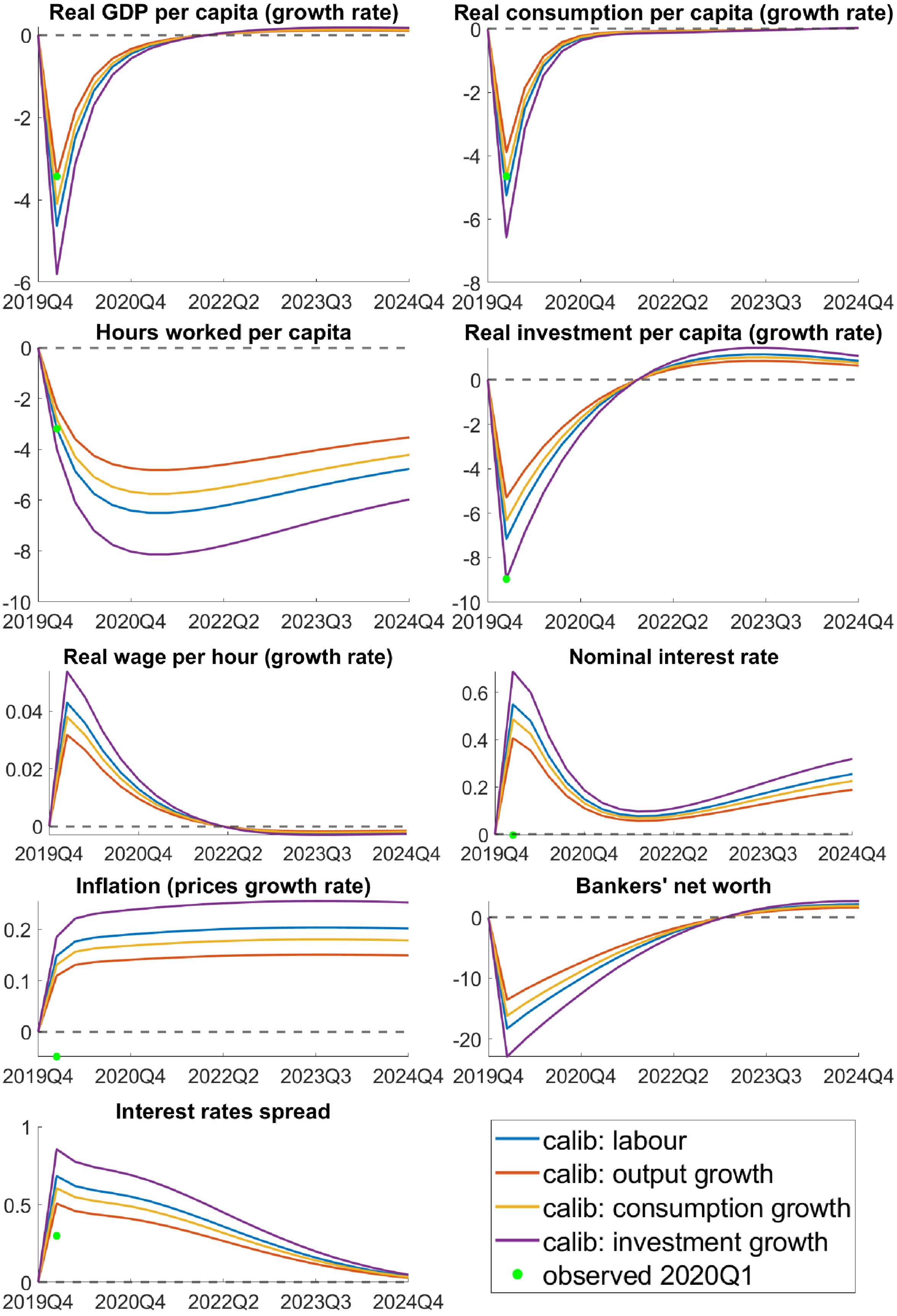
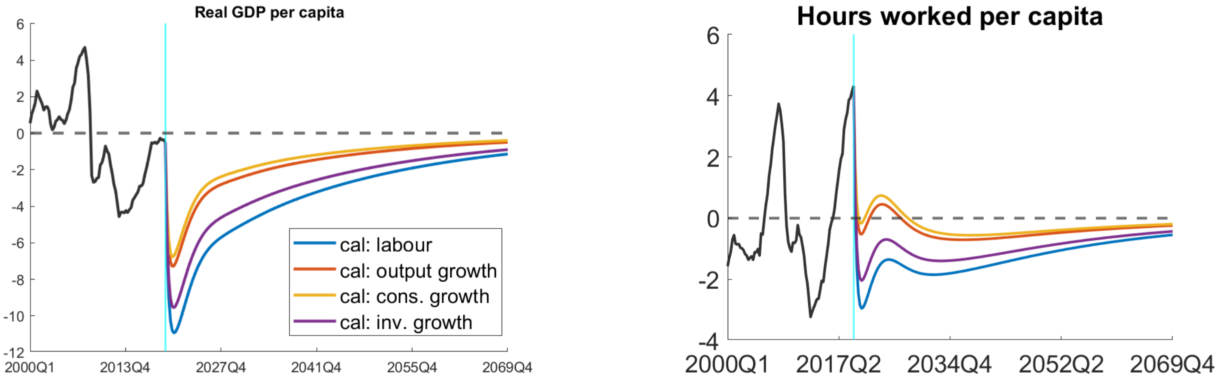


Figure 5 shows the simulated output and hours worked since the beginning of the century and for the next 50 years. Notice that both series are in levels, not in growth rates. They reveal that, unless there are new exogenous stimuli or expansionary policies are applied, the economy will take a long time to get back to pre-crisis levels. Moreover, variables that were over their steady state values before the coronavirus outbreak, like labour, in normal circumstances will not reach again the same situation. Instead, they will converge to their steady states. Figure 11 in Appendix VI contains the simulated patterns for the rest of time series in levels. The long time that most variables require to arrive to their steady states reflects the seriousness of the disturbance that this pandemic has entailed. Our results can be compared to those obtained by Mihailov (2020). They would be situated in his most severe scenario, which considers the effects of the pandemic as highly persistent. In other scenarios he sets out, the recovery would be relatively fast, even in levels.

Figure 5

Convergence to steady state after pandemic shock ($\rho_l = 0.991$)



6 Quantitative easing programme

Many central banks around the world are engaging in quantitative easing (QE) interventions in order to mitigate the effects of the crisis after COVID-19 outbreak (Hartley and Rebucci, 2020). This is a form of unconventional monetary policy in which central banks seek to increase money supply, usually through large-scale assets purchases.

In the literature, some authors have integrated quantitative easing programmes endogenously in DSGE models.[6] We take a simpler approach and model it as an exogenous disturbance, as we are mostly interested in the analysis of the consequences of an occasional use of this tool to counterbalance the crisis. In other words, we consider these large-scale assets purchases as a one-off event. This approach does not seem inappropriate: due to the exceptional nature of the circumstances, we can expect measures of relative size greatly superior to those adopted in any normal situation.

In the model, firms borrow funds from financial intermediaries. The cost of the operation depends on the financial situation of bankers, which is considerably worrisome at present. They have little liquidity and, therefore, borrowing is costly and investment will fall. Against that, the European Central Bank (ECB) is injecting large amounts of money, thus reducing the costs of borrowing and partly counterbalancing the fall in investment. Nevertheless, all that liquidity translates into an increase in the aggregate demand and, unavoidably, in inflation. Summarising, this policy implies a potential trade-off between output recovery and control of prices. In consequence, it cannot be used at will: the possibilities are limited by ECB's inflation target.

To introduce quantitative easing policies, we need to come back to the banking sector. In previous sections we had $Q_t S_t = \phi_t N_{j,t}$. Now, let us assume that the demand for assets is not only privately intermediated any longer, but the central bank is also willing to facilitate lending. Thus, just as in Gertler and Karadi (2011):

$$Q_t S_t = Q_t S_{p,t} + Q_t S_{g,t} = \phi_t N_{j,t} + Q_t S_{g,t},$$

where $Q_t S_{p,t}$ is the amount of assets intermediated via private banks, $Q_t S_{g,t}$ is the value of governmentally assisted assets, and $Q_t S_t$ is the total quantity of intermediated assets. Public share of this total amount is given by ψ_t. Therefore, $Q_t S_{g,t} = \psi_t Q_t S_t$.

The QE policy consists of periodical injections of liquidity into the economy. It starts with a big intervention but in the following periods authorities progressively reduce the quantities. As previously announced, we address the inclusion of this policy with a new exogenous disturbance. The magnitude of the shock dictates the amounts of money offered, whereas the persistence determines the duration of the intervention. We consider three possibilities: half-year, one-year and two-year programmes, and we adjust all of them to be compatible with the European Central Bank's inflation target. Figure 6 contains the impulse-response functions associated with the QE shock. Noteworthy, we find a trade-off between control of inflation and output recovery, as expected. The three possibilities show similar effects. Apparently, the length of the programmes is not as relevant as the amount of money eventually injected. In view of these graphs, QE could be an adequate response to this emergency, as it indeed mitigates the effects of the recession, at the cost of a rise in inflation.

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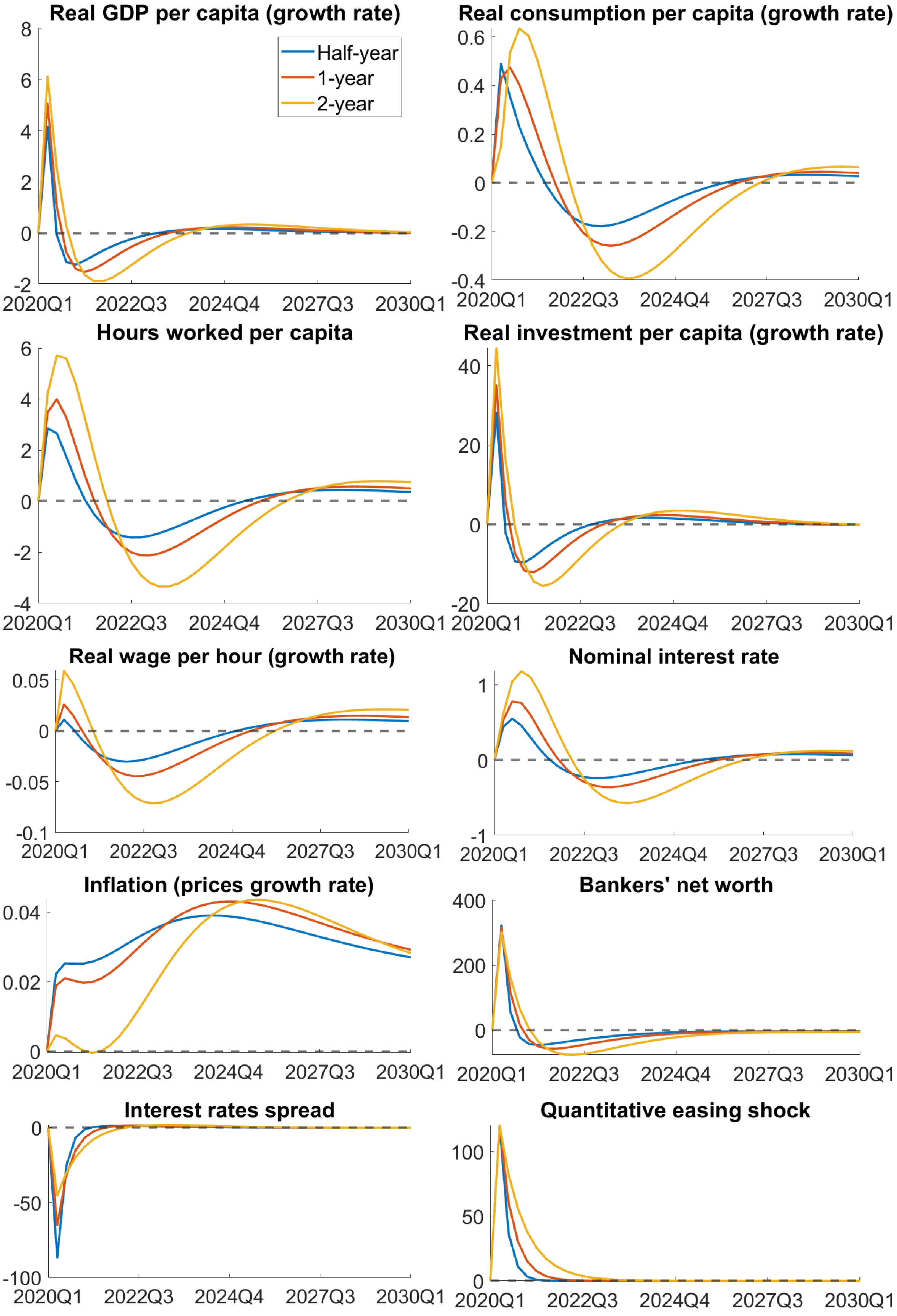
[6] Some examples are Gertler and Karadi (2013), whose model is very similar as the one in Gertler and Karadi (2011), on which our financial frictions are grounded; and Hohberger, Priftis, and Vogel (2019), who implement an open economy to account for variations in the exchange rates as a consequence of quantitative easing policies.

Figure 6

Impulse-Response functions for different quantitative easing programmes


Real GDP per capita (growth rate)

Real consumption per capita (growth rate)

Hours worked per capita

Real investment per capita (growth rate)

Real wage per hour (growth rate)

Nominal interest rate

Inflation (prices growth rate)

Bankers' net worth

Interest rates spread

Quantitative easing shock

Figure 7

Post-confinement reactions to a quantitative easing programme (I)

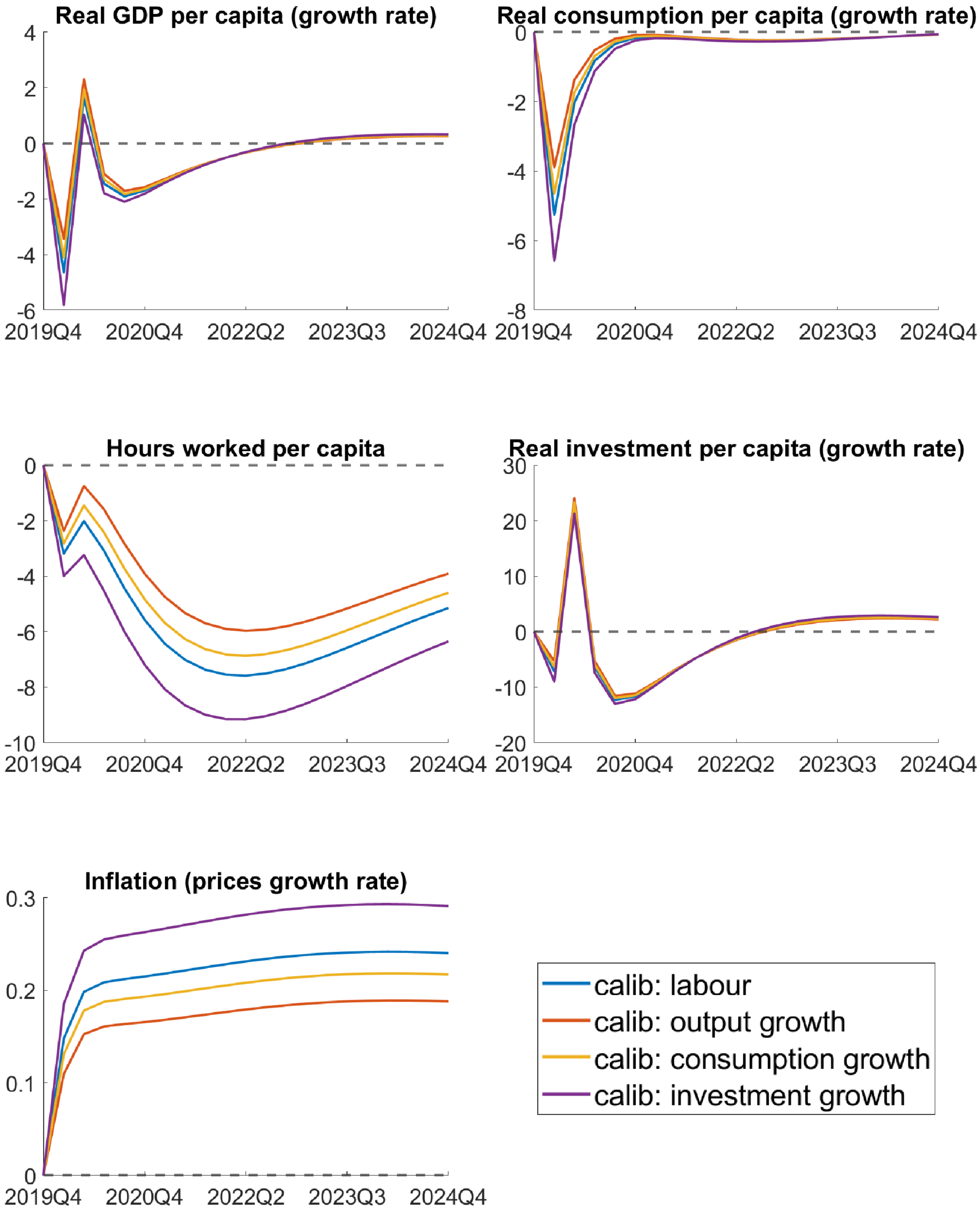
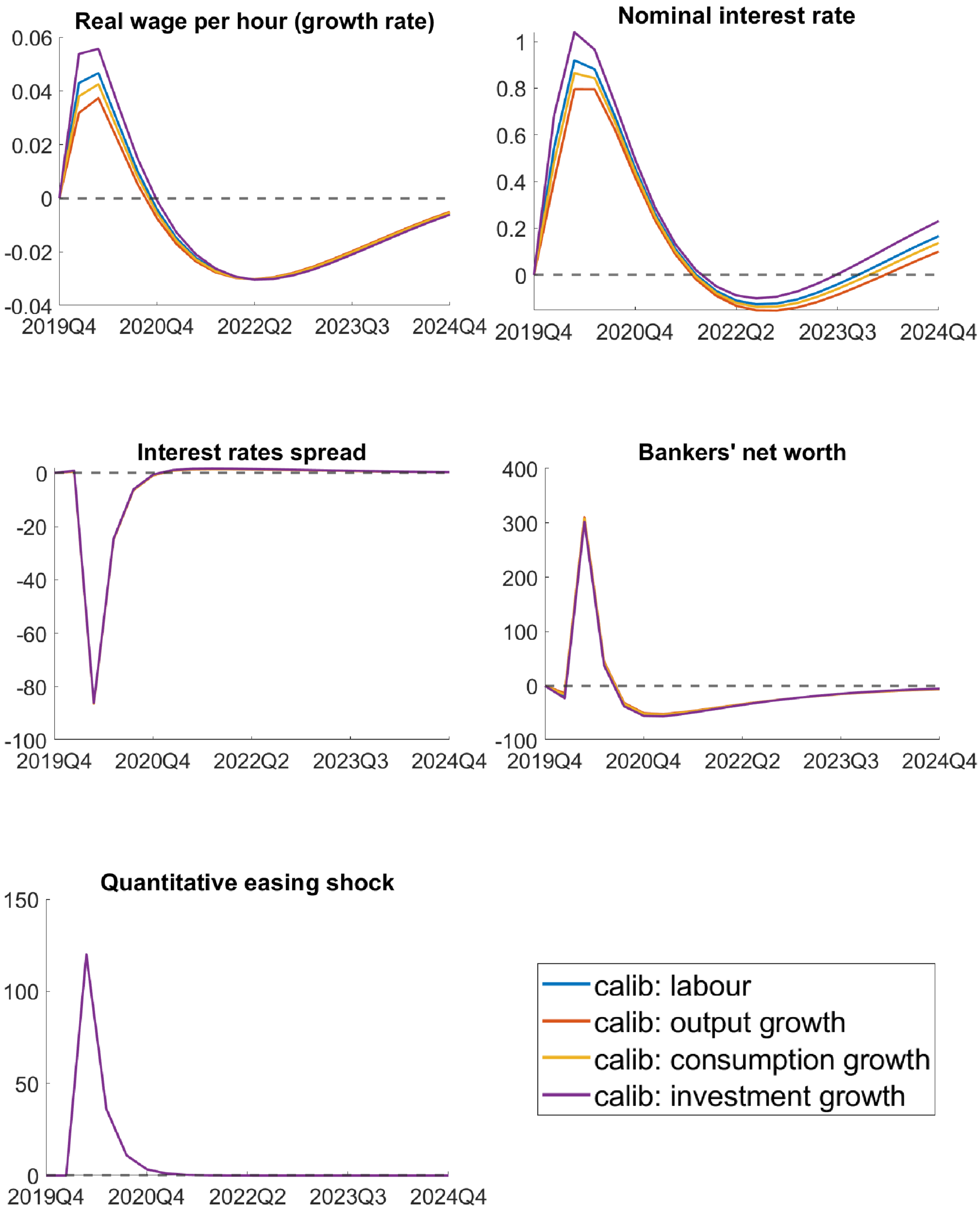


Figure 8

Post-confinement reactions to a quantitative easing programme (II)



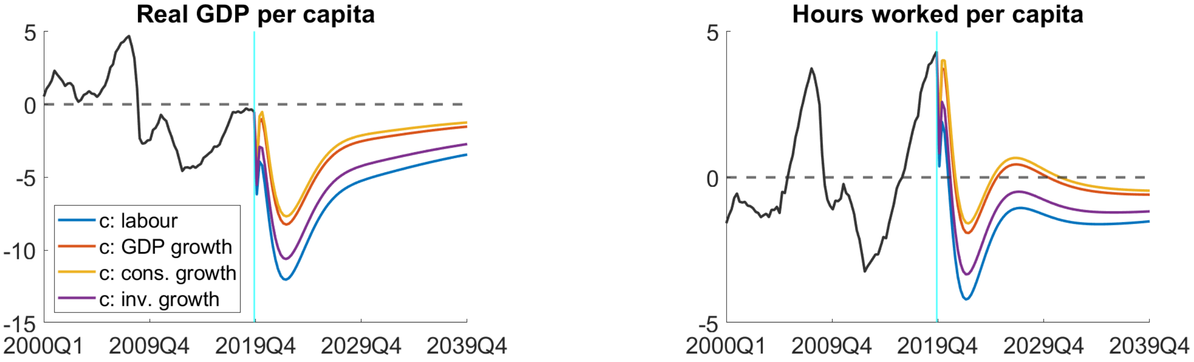
In order to analyse how effective the QE policy can be under the current circumstances, we repeat the exercise but now accounting for the shock to the labour supply. We reintroduce the four different calibrations that we set up in the previous section. This time we only consider the QE programme featured by the intermediate option of one-year length. We adjust the magnitude of the intervention in order to maximise output recovery without exceeding ECB's inflation restrictions. Besides, we assume that these actions are taken from 2020Q2 onwards, *i.e.* they start one quarter after the pandemic shock. Figures 7 and 8 show how the economy after confinement will react when authorities introduce this measure. When compared with the IRFs in Figure 4, they reveal substantial effects in the short run. Output would immediately change its course, even reaching positive growth. Consumption is barely affected by the intermediation, but labour does show improvements in the short run. Investment reaches a positive peak right after the introduction of the policy. Likewise, real wages and nominal interest rate receive upward pressure. With respect to the financial sector, the measure results in an abrupt reduction of credit costs, consistent with the remarkable expansion of money supply. Bankers also receive a momentary boost. The raise in inflation is the cost paid to mitigate the economic damage caused by the pandemic. The calibrations for labour and consumption growth would imply that the QE plan is within ECB's inflation target, whereas if eventually the calibration for output growth turns out to be the most accurate, there would be some free room to increase the size of these money injections. Under the calibration for investment growth, the programme would be slightly over ECB's objective, but it may be affordable under these circumstances.

Nevertheless, when we shift our attention to the long term, we find that the effects of this policy rapidly vanish. After some years, the simulated time series patterns do not exhibit substantial changes with respect to the situation with no unconventional monetary policy. The economy would still need an unsatisfactory amount of time to approach its steady state. It can be clearly observed when comparing Figures 9 and 5. Similar simulated patterns for the rest of variables can be found in Figure 11, in Appendix VI.

Hence, we can conclude that QE helps mitigating the harmful economic repercussions of the pandemic. However, for its restoring effects to be durable, the intervention should be strikingly significant or sustained over time. Such strategy would not be assumable given the current restrictions that the European Central Bank imposes with its inflation target. In consequence, QE measures can be considered for a momentary offset of the recession, but not as a long-standing solution. Therefore, they should be accompanied by other actions meeting the medium and long-run needs that this dramatic event has prompted.

Figure 9

Convergence to steady state after the pandemic shock ($\rho_l = 0.991$) and a quantitative easing policy



7 Conclusions

The worldwide spread of coronavirus took most of us by surprise. Including governments, which were forced to improvise in their approaches to cope with the pandemic. And against such a transcendental mission as it was minimising costs in human lives, the economy was somewhat relegated to second place in decision-making processes. Productive activities were largely frozen and social interactions reduced to a minimum.

In the previous pages we comment on the economic consequences of these measures. We characterise the economy of the Euro Area with a medium-scale DSGE model. In order to replicate the impact of confinement, we make use of an exogenous disturbance to the supply of labour of stunning magnitude. Relying on the results of the estimation, and including this unexpected pandemic shock, we carry out several simulations in which we account for different possible calibrations. We find out that they all point to a relatively fast recovery in growth rates. However, the bounce-back effect is too small. Therefore, without unusually high growth rates in the following years, the levels of the economic variables are condemned to a long-lasting process of convergence to their steady state values.

These predictions give room for the adoption of new extraordinary measures to counterbalance those adopted in the previous months. Many central banks are opting for quantitative easing initiatives. We adapt the model for that possibility with a new exogenous disturbance hitting the market for assets, thus allowing authorities to inject additional funds into the economy. We simulate the effects that such intervention can have in the economy within the framework of our model. Unfortunately, this policy implies a trade-off between control of inflation and output recovery, and therefore its use is restricted by central banks' inflation targets.

We carry out a simulation exercise in which, keeping the pandemic shock, we calibrate a possible one-year quantitative easing programme in such a way that it maximises output recovery without exceeding European Central Bank's objectives of inflation. In light of our results, we conclude that quantitative easing helps mitigating the harmful economic repercussions of the stop in production activities imposed during the confinement. However, these restoring effects are ephemeral. Quantitative easing measures are adequate for an immediate neutralization of the recession, but they should not be seen as a silver bullet for the recovery. Unless they are accompanied by additional measures with focus on the medium and long run, the economy will not be able to get back to pre-crisis levels in a reasonable amount of time.

It should be noticed that our results are based on a single shock. Even though we assume it will be highly persistent, new outbreaks and measures of confinement may alter their accuracy. Besides, we only have one period of data available since the pandemic, 2020Q1. This may translate into a poor calibration of the shock. When new observations appear and the preliminary ones are revised, we will be able to improve the calibration and, therefore, the reliability of the simulation pattern. It could even be necessary to incorporate other perturbations together with the labour supply disturbance in order to emulate properly the repercussions of confinement. It would be interesting to repeat the analysis in other economic areas, for the sake of robustness. Moreover, the model could be further developed with the inclusion of heterogeneous agents, in order to account for the rise in inequality that the shock is causing due to its irregular impact across different economic sectors. Still, we hope that this work will provide a general insight of the economic situation after the pandemic and that it will serve as a basis for deeper research within the framework of DSGE modelling.

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Appendices

Appendix I log-linearised model

At equilibrium, all agents behave optimally and all markets clear. Under these assumptions, the economy is characterised by the first-order conditions derived from the maximisation problems. There is one additional step needed before out the estimation through Bayesian methods: we have to log-linearise these conditions. In this section we show the resulting log-linearised equations, which we finally introduce into Dynare. In general, they are the same as in Gelain and Ilbas (2017), with a few modifications.

From households' decision we obtain the following Euler equation:

$$c_t = \frac{\lambda/\gamma}{1+\lambda/\gamma}c_{t-1} + \frac{1}{1+\lambda/\gamma}E_t c_{t+1} + \frac{(\sigma_c - 1)\left(W_*^h L_*/C_*\right)}{\sigma_c\left(1+\lambda/\gamma\right)}(l_t - E_t l_{t+1}) - \frac{1-\lambda/\gamma}{\sigma_c\left(1+\lambda/\gamma\right)}\left(r_t - E_t\pi_{t+1} + \varepsilon_t^b\right),$$

being γ the steady state growth rate, σ_c the intertemporal elasticity of substitution, λ a habit parameter and $(r_t - E_t\pi_{t+1})$ the *ex-ante* real interest rate. c_t and l_t are the first log-differences of consumption and labour at period t, whereas π_t is inflation and r_t the nominal interest rate. ε_t^b is an exogenous disturbance related to the difference between the interest rate and the return on assets that households request. Parameters with subindex $*$ represent the steady state values of their respective variables.

From labour unions' problem we derive the wage setting equation:

$$w_t = \frac{1}{1+\bar{\beta}}w_{t-1} + \frac{\bar{\beta}}{1+\bar{\beta}}(E_t w_{t+1} + E_t\pi_{t+1}) - \frac{1+\bar{\beta}\iota_w}{1+\bar{\beta}}\pi_t + \frac{\iota_w}{1+\bar{\beta}}\pi_{t-1} - \frac{\left(1-\bar{\beta}\xi_w\right)(1-\xi_w)}{\left(1+\bar{\beta}\right)\xi_w\left[(\phi_w - 1)\varepsilon_w + 1\right]}\mu_t^w + \varepsilon_t^w,$$

where $\bar{\beta} = \beta\gamma^{1-\sigma_c}$, being β the households' discount factor. ξ_w is the Calvo-probability that the union can change wages at a given time. Wages that cannot be re-optimised are partially indexed to the past inflation rate through ι_w. ε_w represents the curvature of the Kimball aggregator for the labour market and $(\phi_w - 1)$ is a constant mark-up in this market.

μ_t^w is the wage mark-up, given by:

$$\mu_t^w = w_t - mrs_t = w_t - \left[\sigma_l(\varepsilon_t^l + l_t) + \frac{1}{1-\lambda}\left(c_t - \lambda c_{t-1}\right)\right],$$

i.e. by the difference between the real wage in first log-differences (w_t) and the marginal rate of substitution between labour and consumption. σ_l is the elasticity of labour supply with respect to the real wage. Two shocks intervene here. On the one hand a wage mark-up shock, ε_t^w. On the other hand, ε_t^l is the perturbation in the supply of labour, which we use to approximate the effects of confinement.

Additionally, the log-linear investment (i_t) is retrieved from its own Euler equation:

$$i_t = \frac{1}{1+\bar{\beta}}i_{t-1} + \frac{\bar{\beta}}{1+\bar{\beta}}E_t i_{t+1} + \frac{1}{(1+\bar{\beta})\gamma^2\varphi}q_t + \varepsilon_t^i,$$

where φ is the elasticity of the capital adjustment cost function at the steady state and ε_t^i the investment-specific technology shock. q_t is the real value of capital, which can be derived from:

$$ret_t^k = \frac{R_*^k}{R_*^k + 1 - \delta}r_t^k + \frac{1-\delta}{R_*^k + 1 - \delta}q_t - q_{t-1} - \varepsilon_{t-1}^b,$$

being δ and r_t^k the capital depreciation rate and rental rate, respectively. ret_t^k is the gross return to capital. k_t^s is a measure of capital services used in production, which depends on the utilisation rate of capital (z_t) and on capital installed in the previous period: $k_t^s = k_{t-1} + z_t$. At the same time, the capital utilisation rate is given by: $z_t = \frac{1-\psi}{\psi}$, with ψ a positive function of the elasticity of the capital utilisation adjustment costs.

The law of accumulation of capital is:

$$k_t = \frac{1-\delta}{\gamma} k_{t-1} + \frac{\gamma - 1 + \delta}{\gamma} i_t + \left(1 - \frac{1-\delta}{\gamma}\right)(1+\bar{\beta})\gamma^2 \varphi \varepsilon_t^i.$$

The New-Keynesian Phillips curve comes from intermediate goods producers problem:

$$\pi_t = \frac{\bar{\beta}\iota_p}{1+\bar{\beta}\iota_p}\pi_{t-1} + \frac{1}{1+\bar{\beta}\iota_p}E_t\pi_{t+1} - \frac{\left(1-\bar{\beta}\xi_p\right)(1-\xi_p)}{\left(1+\bar{\beta}\iota_p\right)\xi_p\left[(\phi_p - 1)\varepsilon_p + 1\right]}\mu_t^p + \varepsilon_t^p,$$

where ι_p is the indexation parameter, ξ_p the Calvo-probability that a firm is allowed to re-optimise prices at a given period, ε_p the curvature of the Kimball aggregator for the goods market and $(\phi_p - 1)$ the constant mark-up in this market. ε_t^p is the price mark-up shock.

μ_t^p is the price mark-up, determined by the difference between the marginal product of labour and the real wage:

$$\mu_t^p = mpl_t w_t = \alpha(k_t^s - l_t) + \varepsilon_t^a - w_t,$$

where ε_t^a is the total factor productivity, modelled as an exogenous perturbation.

And from the minimisation of costs, the rental rate of capital is defined as:

$$r_t^k = w_t + l_t - k_t^s.$$

Equilibrium in the goods market implies that only what is produced can be consumed, with different possible end uses. Then, this restriction can be divided in two equations. Firstly, on the production side,

$$y_t = \phi_p\left[\alpha k_t^s + (1-\alpha)l_t + \varepsilon_t^a\right].$$

Secondly, on the allocation side,

$$y_t = c_y c_t + i_y i_t + z_y z_t + g_y \varepsilon_t^g.$$

y_t is the first log-differences of aggregate output; c_y, i_y, z_y and g_y are the shares of output that the different forms of consumption represent at the steady state. Exogenous spending comprises other uses for the production, mainly government's resources and international trade. It is modelled as an exogenous shock.

The central bank decides its conventional monetary policy following a Taylor rule:

$$r_t = \rho_r r_{t-1} + (1-\rho_r)\left[r_\pi \pi_t + r_y(y_t - y_t^p)\right] + r_{\Delta y}\left[(y_t - y_t^p) - (y_{t-1} - y_{t-1}^p)\right] + \varepsilon_t^r,$$

where ε_t^r is a monetary policy shock and $(y_t - y_t^p)$ is the output gap. For its computation, we assume that the potential output, y_t^p is the one achieved in an economy without rigidities.

The log-linearised balance sheet of financial intermediaries is:

$$q_t + s_t = n_S n_t + b_S b_t,$$

being s_t the amount of long-term financial claims that the banker owns, n_t represents intermediaries' equity capital and b_t the short-term deposits from families. Finally, $n_S = {}^{N_*}/_{S_*}$ and $b_S = {}^{B_*}/_{S_*}$.

Arbitrage implies that the value of capital acquired by firms and the value of claims against such capital are the same:

$$q_t + k_t = q_t + s_t.$$

Additionally, the real gross return is given by a Fisher equation:

$$rr_t = r_t - E_t \pi_{t+1} + \varepsilon_t^b.$$

Intermediaries' leverage (lev_t) is given by:

$$lev_t = \eta_t - \frac{\Gamma_*}{\Gamma_* - \upsilon_*}\Gamma_t - \frac{\upsilon_*}{\Gamma_* - \upsilon_*}\upsilon_t,$$

where Γ_t is the fraction of funds that the intermediary may divert at a given time, which is taken as an exogenous disturbance. η_t represents the expected value of future net worth and υ_t the expected gains for the intermediaries from expanding assets. They are respectively described by:

$$\begin{aligned}
\eta_t &= \frac{\beta(1-\theta)\overline{RR}_*}{\gamma^{\sigma_c}\eta_*}\left(E_t U_{t+1}^c - U_t^c + rr_t\right) + \frac{\beta}{\gamma^{\sigma_c}}\theta Z_*^{GK} E_t\left(U_{t+1}^c - U_t^c + z_{t,t+1}^{GK} + \eta_{t+1}\right), \\
\upsilon_t &= \frac{\beta(1-\theta)}{\gamma^{\sigma_c}\upsilon_*}\left[\left(\overline{ret}_*^k E_t ret_{t+1}^k - \overline{RR}_* rr_t\right) + \left(\overline{ret}_*^k - \overline{RR}_*\right)\left(E_t U_{t+1}^c - U_t^c\right)\right] + \frac{\beta}{\gamma^{\sigma_c}}\theta X_* E_t\left(U_{t+1}^c - U_t^c + x_{t,t+1} + \upsilon_{t+1}\right),
\end{aligned}$$

where θ is the fraction of bankers that remain in the sector, $z_{t,t+1}^{GK}$ is the gross growth rate of net worth, $x_{t,t+1}$ is the gross growth rate in assets between periods t and $t+1$, and U_t^c is marginal utility of consumption. They are characterised by the equations:

$$\begin{aligned}
z_{t-1,t}^{GK} &= \frac{\overline{lev}_*}{Z_*^{GK}}\left(\overline{ret}_*^k ret_t^k - \overline{RR}_* rr_{t-1}\right) + \frac{\overline{lev}_*\left(\overline{ret}_*^k - \overline{RR}_*\right)}{Z_*^{GK}} lev_{t-1} + \frac{\overline{RR}_*}{Z_*^{GK}} rr_{t-1}, \\
x_{t-1,t} &= lev_t - lev_{t-1} + z_{t-1,t}^{GK}, \\
U_t^c &= (\sigma_c - 1) L_*^{1+\sigma_l}(\varepsilon_t^l + l_t) - \frac{\sigma_c}{1-\lambda} c_t + \frac{\sigma_c \lambda}{\gamma(1-\lambda)} c_{t-1}.
\end{aligned}$$

The relation between depositors and bankers is limited by an agency problem:

$$q_t + k_t^s = lev_t + n_t.$$

In Section 6, where we analyse the consequences of implementing a quantitative easing programme, we transform the previous condition into:

$$q_t + k_t^s = lev_t + n_t + \varepsilon_t^{qe}.$$

where ε_t^{qe} is an exogenous disturbance that we introduce to emulate the adoption of this kind of unconventional monetary policy.

Bankers' net worth is the sum of existing intermediaries net worth ($n_{e,t}$) and entering bankers net worth ($n_{n,t}$):

$$n_t = \frac{\overline{NE}_*}{N_*} n_{e,t} + \frac{\overline{NN}_*}{N_*} n_{n,t} + \varepsilon_t^{nw},$$

where ε_t^{nw} is an exogenous disturbance to net worth that we introduce. And since a proportion θ of bankers remain in the financial activities, their equity capital is given by: $n_{e,t} = z_{t-1,t}^{GK} + n_{t-1}$.

Households transfer an amount of money to their new bankers, proportional to the funds from exiting bankers, leading to:

$$n_{n,t} = q_t + k_t^s.$$

Finally, bankers' profits come from the premium they earn on their assets:

$$Prem_t = E_t ret_{t+1}^k.$$

Appendix II exogenous disturbances

The economy we have presented is exogenously influenced by several shocks. Below, a brief summary of their purpose and how they are modelled:

(i) Price mark-up shock (ε_t^p). It affects the gap between the average price and the nominal marginal cost. It is described by an exogenous ARMA(1,1) structure: $\varepsilon_t^p = \rho_p \varepsilon_{t-1}^p + \eta_t^p - \mu_p \eta_{t-1}^p$.

(ii) Total factor productivity (ε_t^a). It represents variations in technology and affects directly output and the price mark-up. It follows an exogenous AR(1) process: $\varepsilon_t^a = \rho_a \varepsilon_{t-1}^a + \eta_t^a$.

(iii) Labour supply shock (ε_t^l). It reflects changes in preferences on labour and leisure. It is the one we use to approximate the economic effects of COVID-19 confinement. This disturbance is characterised by an exogenous AR(1): $\varepsilon_t^l = \rho_l \varepsilon_{t-1}^l + \eta_t^l$.

(iv) Risk premium shock (ε_t^b). This exogenous disturbance captures the wedge between the interest rate set by the central bank and the return on assets that households require. It is modelled through an exogenous AR(1) process: $\varepsilon_t^b = \rho_b \varepsilon_{t-1}^b + \eta_t^b$.

(v) Investment shock (ε_t^i). It affects directly investment and capital accumulation. It also follows an exogenous AR(1): $\varepsilon_t^i = \rho_i \varepsilon_{t-1}^i + \eta_t^i$.

(vi) Financial shock (Γ_t). It represents depositors' beliefs about the extent to which they will be able to recover their investment. The structure of this shock is an exogenous AR(1): $\Gamma_t = \rho_\Gamma \Gamma_{t-1} + \eta_t^\Gamma$

(vii) Net worth shock (ε_t^{nw}). Another disturbance in the financial sector, in this case affecting bankers' equity. It is defined by an exogenous AR(1): $\varepsilon_t^{nw} = \rho_{nw} \varepsilon_{t-1}^{nw} + \eta_t^{nw}$.

(viii) Wage mark-up shock (ε_t^w). It reflects hits to the difference between the real wage and the marginal rate of substitution. Its characteristic equation is an exogenous ARMA(1,1): $\varepsilon_t^w = \rho_w \varepsilon_{t-1}^w + \eta_t^w - \mu_w \eta_{t-1}^w$.

(ix) Monetary policy shock (ε_t^r). It captures variations in monetary policy and in its effectiveness, following an exogenous AR(1) process: $\varepsilon_t^r = \rho_R \varepsilon_{t-1}^r + \eta_t^r$.

(x) Exogenous spending (ε_t^g). It accounts for alterations in government's policies and for international trade, which can be impulsed by technological shocks. By including the productivity innovation, it captures the effects of variations in technology for competitiveness in an open economy. It is characterised by the process: $\varepsilon_t^g = \rho_g \varepsilon_{t-1}^g + \eta_t^g + \rho_{g,a} \eta_t^a$.

(xi) Quantitative easing programme (ε_t^{qe}). We only use it for our final assessment of the effects of a quantitative easing initiative. It follows an exogenous AR(1) process: $\varepsilon_t^{qe} = \rho_{qe} \varepsilon_{t-1}^{qe} + \eta_t^{qe}$

Appendix III database

As already mentioned, our set of macroeconomic variables is the equivalent for the Euro Area of the one used by Smets and Wouters (2007). More precisely, we made use of the following series:

- Real GDP: chain linked volumes with base in 2010, seasonally and calendar adjusted and measured in million euro. Series code: Q.CLV10_MEUR.SCA.B1GQ.EA19.

- GDP deflator: price index with base in 2010. It is already seasonally and calendar adjusted. We will use it as a measure of inflation. Series code: Q.PD10_EUR.SCA.B1GQ.EA19.

- Real consumption: chain linked volumes with base in 2010, seasonally and calendar adjusted and measured in million euro. Series code: Q.CLV10_MEUR.SCA.P31_S14_S15.EA19.

- Real investment: chain linked volumes with base in 2010, seasonally and calendar adjusted and measured in million euro. Series code: Q.CLV10_MEUR.SCA.P51G.EA19.

- Wages: at current prices, seasonally and calendar adjusted and measured in million euro. Series code: Q.CLV10_MEUR.SCA.P51G.EA19.

- Hours worked: seasonally and calendar adjusted. It encompasses all activities in the economy. Measured in thousand hours worked. Series code: Q.THS_HW.TOTAL.SCA.EMP_DC.EA19.

- Nominal interest: 3 month rate. Series code: Q.IRT_M3.EA.

- Population: measured in thousand people aged between 15 and 64, to work with the size of the labour force. Series code: Q.THS.T.TOTAL.Y1564.POP.EA19.

All the series correspond to the aggregate of the 19 current members in the Euro Area, even before they gained admission into it.[7] The sole exception is the interest rate. In this case, we are using the rate applied in the Euro Area, whatever its composition at each specific time. Given that population series start in 2003, we rely on Brand and Toulemond's (2015) approach. They join the separated population series up to 2003 for the current members of the Euro Area and afterwards they append this combination to the recent data. Eventually, they apply the Hodrick-Prescott filter to smooth the series.

In the characterisation of the financial expansion, initially we considered to incorporate the variables net worth and credit spread, just as in Gelain and Ilbas (2017). However, eventually we could only use the latter. Unfortunately, we did not find any suitable net worth time series dating back to year 2000. Among others, we used Eurostat's measure for total assets/liabilities in their financial balance sheets (series code: nasq_ 10_ f_ bs) and other similar series from the European Central Bank. Consequently we opted for letting the model itself estimate the net worth without using an observable measure for it.

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[7] The composition of the Euro Area has not been constant over this time. There were 11 countries when it was created, and the other 8 have gained entry along these two decades. The series we use include all the 19 countries during the whole sample period, as if in year 2000 the Euro Area were already composed by all of them. Otherwise, our results would be affected by changes in the composition of the monetary union.

Appendix IV estimation output

Table 3

Estimation output: parameters

	Prior distribution			Posterior distribution			
	Distr.	Mean	St. Dev.	Mode	Mean	5%	95%
ρ_a	Beta	0.50	0.20	0.9706	0.9689	0.9488	0.9893
ρ_b	Beta	0.50	0.20	0.9792	0.9747	0.9598	0.9902
ρ_g	Beta	0.50	0.20	0.8105	0.8148	0.7244	0.9082
ρ_i	Beta	0.50	0.20	0.9290	0.9250	0.9093	0.9415
ρ_R	Beta	0.50	0.20	0.1144	0.2295	0.0100	0.5007
ρ_Γ	Beta	0.50	0.20	0.9506	0.6346	0.4258	0.8328
ρ_l	Beta	0.50	0.20	0.9956	0.9910	0.9829	0.9988
ρ_{nw}	Beta	0.50	0.20	0.4709	0.9558	0.9350	0.9928
ρ_p	Beta	0.50	0.20	0.1347	0.1646	0.0255	0.3005
ρ_w	Beta	0.50	0.20	0.1289	0.1643	0.0257	0.2930
μ_p	Beta	0.50	0.20	0.1311	0.1815	0.0219	0.3322
μ_w	Beta	0.50	0.20	0.1287	0.1806	0.0244	0.3297
φ	Normal	4.00	1.50	4.0788	3.6344	1.6384	5.6477
λ	Beta	0.70	0.10	0.4744	0.4561	0.3721	0.5415
ξ_w	Beta	0.50	0.10	0.9190	0.9089	0.8771	0.9413
σ_l	Normal	2.00	0.50	2.4968	2.4927	1.8366	3.1599
ξ_p	Beta	0.50	0.10	0.8945	0.8714	0.8100	0.9322
ι_w	Beta	0.50	0.15	0.2261	0.2523	0.1094	0.3915
ι_p	Beta	0.50	0.15	0.1846	0.1810	0.0625	0.2916
ψ	Beta	0.50	0.15	0.8705	0.8601	0.7894	0.9314
Φ	Normal	1.25	0.13	1.6988	1.7098	1.5628	1.8541
r_π	Normal	1.50	0.25	1.4096	1.5138	1.1070	1.8995
ρ_r	Beta	0.75	0.10	0.9142	0.9117	0.8702	0.9550
r_y	Normal	0.13	0.05	0.1196	0.1061	0.0282	0.1797
$r_{\Delta y}$	Normal	0.13	0.05	0.2417	0.2500	0.1992	0.2998
$\rho_{g,a}$	Normal	0.50	0.25	0.4777	0.4917	0.2371	0.7494
α	Normal	0.30	0.05	0.1679	0.1739	0.1327	0.2127

Table 4

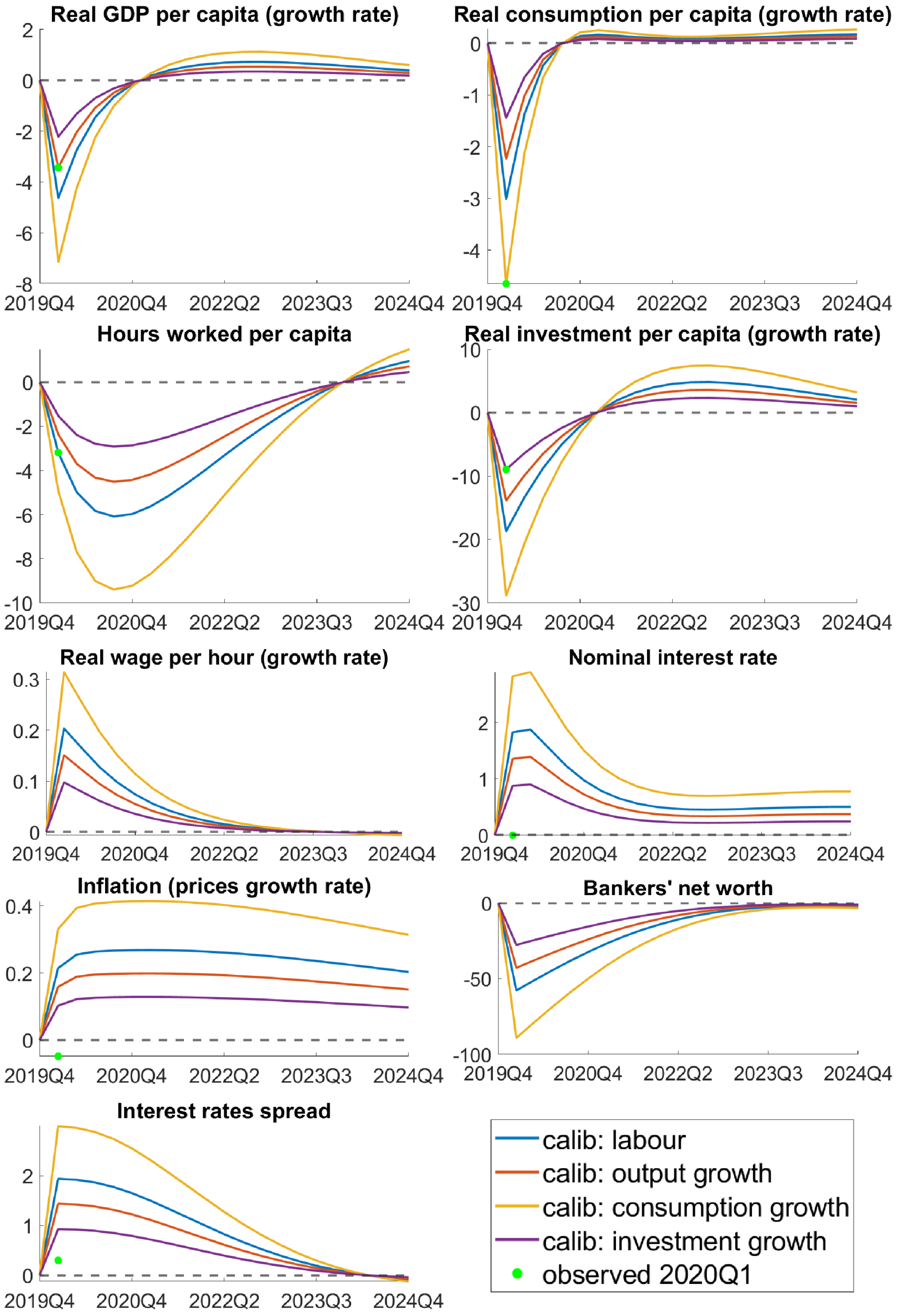
Estimation output: standard deviation of shocks

	Prior distribution			Posterior distribution			
	Distr.	Mean	St. Dev.	Mode	Mean	5%	95%
σ_a	Invgamma	0.10	2.00	0.2364	0.2412	0.2073	0.2750
σ_b	Invgamma	0.10	2.00	0.0285	0.0298	0.0221	0.0373
σ_g	Invgamma	0.10	2.00	0.3618	0.3704	0.3199	0.4190
σ_i	Invgamma	0.10	2.00	0.7034	0.7832	0.5540	1.0126
σ_m	Invgamma	0.10	2.00	0.0571	0.0542	0.0273	0.0770
σ_p	Invgamma	0.10	2.00	0.1286	0.1257	0.1015	0.1503
σ_w	Invgamma	0.10	2.00	0.1019	0.0999	0.0808	0.1191
σ_Γ	Invgamma	0.10	2.00	0.7784	0.0766	0.0247	0.1085
σ_l	Invgamma	0.10	2.00	0.6534	0.6935	0.4955	0.8831
σ_{nw}	Invgamma	0.10	2.00	0.0453	0.0617	0.0450	0.0783

Appendix V robustness figures

Figure 10

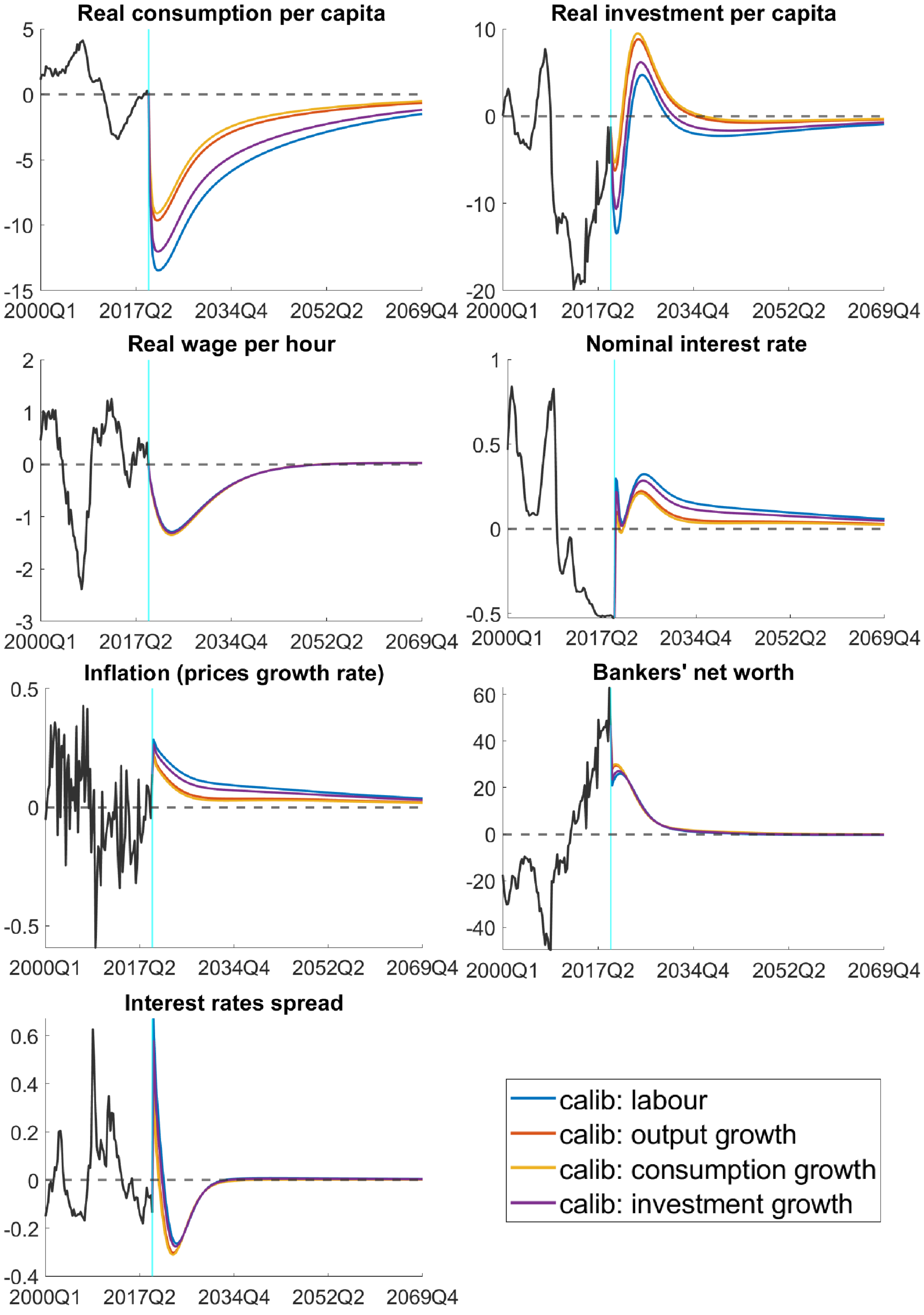
Impulse-Response functions (persistence 0.9)



Appendix VI convergence to steady state

Figure 11

Convergence to steady state after pandemic shock ($\rho_l = 0.991$)



Real consumption per capita

Real investment per capita

Real wage per hour

Nominal interest rate

Inflation (prices growth rate)

Bankers' net worth

Interest rates spread

Figure 12

Convergence to steady state after pandemic shock ($\rho_l = 0.991$) *and a quantitative easing policy*