



ARTICLE



<https://doi.org/10.1057/s41599-023-02030-0>

OPEN

# Monetary policy models: lessons from the Eurozone crisis

Pedro J. Gutiérrez-Diez <sup>1</sup>✉ & Tibor Pál<sup>2</sup>

This paper theoretically and empirically investigates the puzzling decade-long concurrence of expansionary monetary and fiscal policies, decreasing credit flows, fall in price levels, and sluggish real activity observed in the Euro area from the outset of the 2007–2008 financial crisis. To this end, we propose a monetary general equilibrium model that clarifies the transmission mechanisms, debt-deflation channels, and the paramount role of financial leverage decisions underlying these peculiarities. On this basis, a vector error correction model is specified which confirms the theoretical predictions and provides insights into the elements specific to the long-term relations. In addition, the estimated impulse response functions document the associated short-term dynamics outlining the debt-deflation mechanism.

<sup>1</sup>University of Valladolid, Valladolid, Spain. <sup>2</sup>University of Salerno, Fisciano, Italy. ✉email: [pedro.gutierrezdiez@uva.es](mailto:pedro.gutierrezdiez@uva.es)

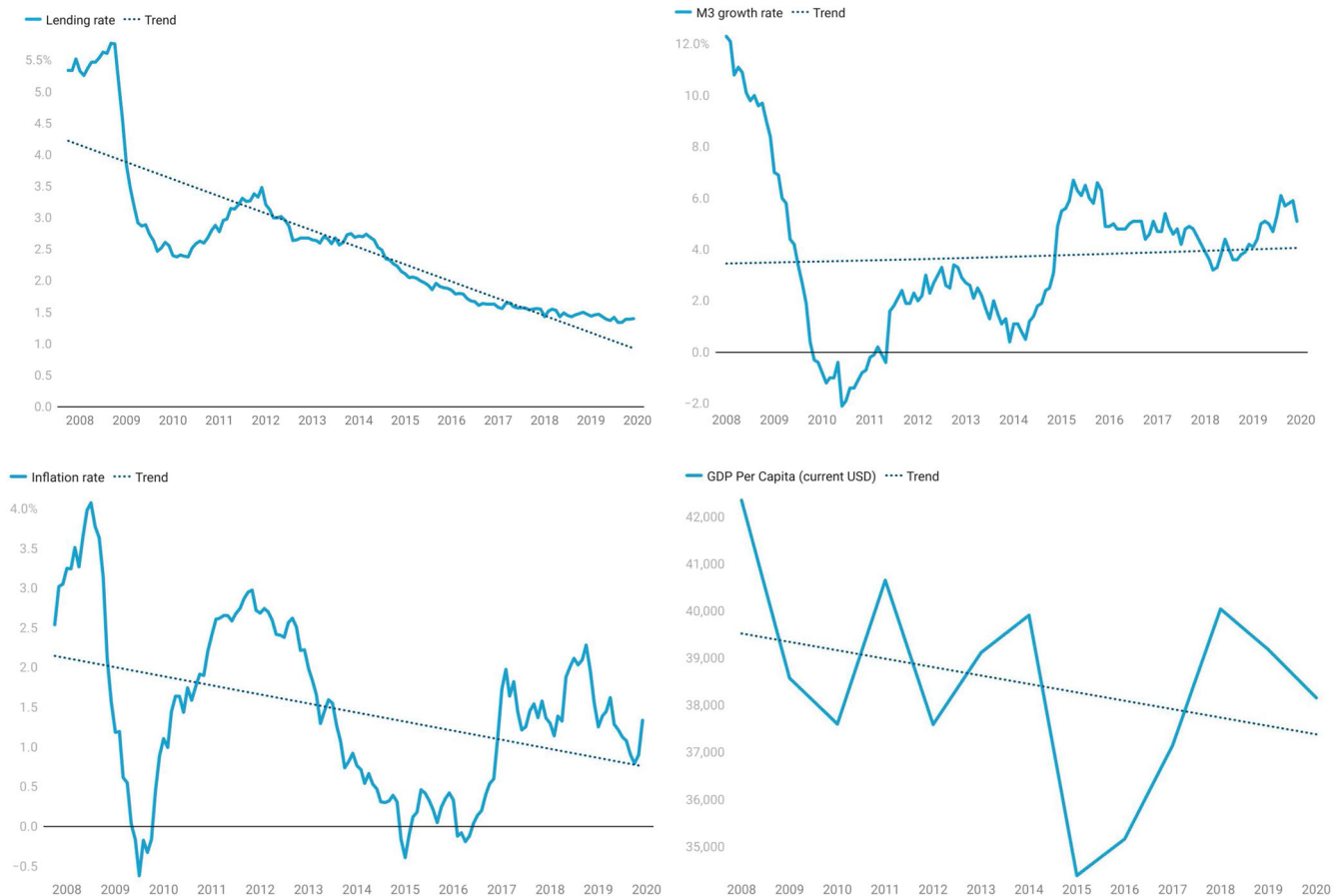
**Background**

Mainly because of the features of the global financial crisis (GFC), economic theory has renewed its concern about how monetary economies are modeled. This especially applies to the Eurozone, where an unusual concurrence of expansionary monetary policies, declining prices, descents in credit flows, and decreases in real activity prevailed for a prolonged period. These facts, shown in Fig. 1, contradict some universally accepted monetary theory principles and raise interesting questions: Why has this long period of expansionary monetary policies not led to the long-run inflationary pressures dictated by the quantitative theory of money? Why have the short-run increases in real activity predicted by limited participation models, inside money models, or Keynesian and new-Keynesian models not occurred? What missing elements need to be considered for consistently modeling the observed effects of the European Central Bank (ECB) monetary policy?

The present paper demonstrates that the answer to these questions primarily lies within the financial aspect of the monetary transmission mechanism. More specifically, our dynamic general equilibrium model (DGEM) shows that the bank credit channel is the crucial element, as it hosts a financial deleveraging process that triggers a debt deflation mechanism that hampers economic activity. The introduced vector error correction model (VECM) confirms the long-run relations driving these phenomena, providing insights into both the long and short-run dynamics.

While existing monetary models can partially explain some of these matters, they cannot reconcile the coexistence of substantial expansionary policies with deflationary pressures and output decreases. For instance, in the quantitative theory of

money, the absence of inflationary effects may appear when the economy is far from full employment and potential output. However, in this scenario, an expansionary environment should have brought long-run real effects unless it is accompanied by a significant decrease in the velocity of money. None of these cases occurred in the 2008–2018 decade. On the contrary, the Eurozone GDP contracted while the velocity of money remained relatively constant (Bussière et al., 2020). Concerning Keynesian and new-Keynesian models, even assuming upward stickiness in prices to account for the absence of inflation, their fundamental pillars—namely the negative dependence of the volume of bank loans on interest rates, and the occurrence of output growth after expansionary monetary and fiscal policies<sup>1</sup>—are not observed. According to the data and as Figs. 1 and 6 depict, neither the sign of the relationship between interest rates and the volume of loans nor that of the interest rates with the GDP growth are those assumed by Keynesian and new-Keynesian models. Indeed, as Deleidi (2018) concludes through a VEC analysis of the 2003–2016 period, the relationship between interest rates and loan aggregates is ambiguous and not univocal in the European economy. In this respect, only mortgage credit appears to be negatively inter-related with the interest rate, the relationship between business loans and loans for household consumption expenditure and the corresponding interest rates being not significant. Interestingly, Deleidi (2018) finds evidence of the relevance of variables, other than interest rates and that summarize credit market conditions, for explaining the total volume of loans. Policies determining financial aspects, such as the macroprudential policies applied in the Eurozone, therefore appear as



**Fig. 1 Eurozone, 2008:2018.** Bank lending rates (upper-left); M3 growth rates (upper-right); Inflation rates (bottom-left); GDP per capita (bottom-right).

potential determinants of the economy's behavior, a relevant issue to which we return in the following sections.

*Fully backed central bank money* models could also theoretically explain the non-appearance of inflation after long periods of expansionary monetary policies. However, the Eurozone is not a fully backed money economy but a fiat money one. Moreover, the absence of inflationary effects in these models requires monetary policy intervention exclusively through open market operations (Champ and Freeman, 2001, ch. 10), which is not the case for the Eurozone. In fact, during the financial crisis period and as described among others by González-Páramo (2009), Ross et al. (2019), and Fiedler and Gern (2019), the ECB response included not only open market operations but also an unconventional toolkit including credit injection, refinancing operations and collateral easing measures. In contrast, *inside money models*<sup>2</sup>, where money backed by private credit circulates as a medium of exchange, appear to explain more consistently the observed deflationary pressures in the Eurozone. As Marimon et al. (2003) and Stracca (2013) conclude, the substitution by households between outside and inside money dampens the inflationary effect of expansionary monetary policies, allowing inside money models to clarify the deflation trend in the Eurozone economy. Nevertheless, one of the main theoretical results of inside money models, viz. the existence of real effects for expansionary monetary policies<sup>3</sup>, conflicts with the empirical evidence found for the Eurozone in the analyzed period.

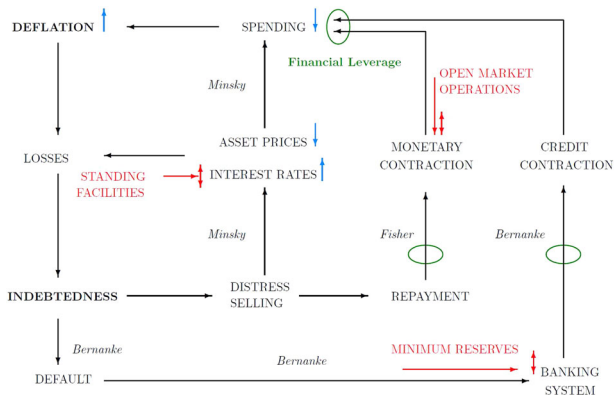
Given the limitation of considering a unique model, finding a coherent explanation of these puzzling relationships between money, interest rates, prices, and output clearly requires a detailed reevaluation of the existing monetary models and a careful selection of the ideas contained therein. Logically, the starting point must be a survey of empirical evidence on the objectives and instruments of the monetary policy relevant to the monetary transmission mechanisms. The analyses in this respect are numerous<sup>4</sup>, and, not surprisingly, a large body of studies focus on the ECB response to the crisis and the peculiarities of the monetary transmission mechanisms in the Eurozone (see, for instance, Angeloni et al., 2002; Drakos and Kouretas, 2015; ECB European Central Bank, 2010; Grandi, 2019; Weber et al., 2009). These studies reveal several salient features instrumental to our purpose: (i) They prove the existence of a continuous and stable inflation targeting by the ECB; (ii) they indicate the unresponsive credit growth for the sharp money supply increases and interest rate descents administered by the ECB; (iii) as several scholars conclude (see for instance, Fiedler and Gern, 2019; Giannone et al., 2019, and the references therein) this breakdown with respect to the established theoretical results is the consequence of significant changes in the monetary transmission mechanisms, or at least in the way they must be modeled; (iv) directly related to the above, the coexistence during the recent crisis of deflation, GDP contraction, and expansive monetary and fiscal policies for the Eurozone economy seems to respond to debt-deflation mechanisms, a crucial issue pointed out by several authors (see the monographs by Baimbridge and Whyman, 2015; Cardinale et al., 2017; Chang et al., 2019); (v) finally, these empirical studies show the increasing relevance of financial elements in the effectiveness of the monetary transmission mechanism and the vital role played by the bank lending channel.

From the empirical perspective, a prominent contribution comes from applying a VECM to analyze the monetary transmission mechanism. As a stable and continuous inflation objective governed by monetary transmission channels is clearly visible, long-run steady relationships must exist linking inflation and those variables controlled by the ECB. In this respect, the VEC model's capability to account for long-run relationships in the system dynamics validates its utilization. To our knowledge,

except for Holtemöller (2004), the empirical literature studying the monetary transmission in the Eurozone—such as that quoted above—exclusively implemented vector autoregressive (VAR) models, omitting the existence of long-run steady relationships or their role in the dynamics. Since the central hypothesis in our analysis is the existence of long-run steady links between the ECB instruments and its inflation target, the VEC model allows us to estimate these relationships and study their role in short- and long-term dynamics. In this regard, Holtemöller (2004) is an immediate reference since, although the considered periods are different, the main conclusion similarly confirms the presence of these long-run stable relationships allowing for systematic and predictable effects of monetary policy. Divergences are minor and arise from the different lengths and characteristics of the considered periods, in particular from the consideration of inferred data for the non-euro 1980–1999 subperiod, with marked distinct trend dynamics resulting from the non-concluded convergence process. Still, these features and his methodological approach to studying the transmission mechanisms operating in the Eurozone provide further motivation towards applying a VEC model.

Several interesting methodological aspects arise from the above-mentioned empirical findings to formulate an appropriate theoretical model. First, the model must explain the empirically identified long-run relationships enabling the monetary policy and linking those variables controlled by the ECB with the inflation rate. Second, the model has to be consistent with the well-documented distinct short-run and long-run effects of monetary policy, the former predominantly real and the latter mainly nominal. Third, it must consider the significant changes in the monetary transmission mechanisms, particularly the presence of the observed debt-deflation channels and the critical role played by the financial sector decisions. The debt-deflation theory postulates a vicious circle linking deflation, descents in bank loans, and decreases in aggregate demand and output. Therefore, according to the declaration of the ECB's inflation objective and its definition of the transmission mechanism, the monetary policy effect must strongly depend on the links between debt-deflation channels, the ECB instruments, and the monetary transmission mechanisms.

In this respect, the ECB has three main monetary policy instruments to achieve its inflation objective: open market operations for controlling money supply, provision of standing facilities for governing interest rates, and minimum reserves requirement aiming at the structural stabilization of financial markets. Concerning debt-deflation theory, the identification of its underlying main channels is due to Fisher (1933), Minsky (1982a, b), and Bernanke (1983). According to Fisher (1933), the starting point is the agent's need to reduce indebtedness. This debt liquidation leads to distress selling, bank loan descents, contractions of deposit currency, and therefore to a subsequent fall in the level of prices through the decrease in the aggregate demand explained by the quantity equation. In such circumstances, deflationary periods can push the economy into a debt-deflation spiral, where the increase in real debt burden leads to reduced aggregate spending, hampering economic recovery. Based on this loop, Minsky (1982a, b) incorporated the consequences for asset markets. In this regard, distressed asset selling can lead to a widespread default when agents fail to realize the funds to meet commitments through the sale of assets due to falling asset prices and elevated interest rates. This prompts further distress selling with additional indebtedness and a lower aggregate demand associated with decreased wealth and higher interest rates. In addition, Bernanke (1983) pointed out that lender defaults also increase, leading to banking problems and the contraction of credit and aggregate investment.



**Fig. 2 Theoretical interactions between ECB policy, debt-deflation, and leverage.** Debt-deflation channels (black), monetary policy instruments (red), and financial leverage (green): theoretical interactions.

In light of these debt-deflation mechanisms, the empirically observed relevance of the financial sector decisions and the credit channel in explaining the puzzling behavior of the Eurozone between 2008 and 2018 can be clarified, at least in part. Simply put, the ineffective translation of the ECB’s monetary expansion into loan aggregates could allow a persistent debt-deflation loop leading to an odd coincidence of money supply increases, interest rate decreases, deflation, and restrained aggregate demand and output. As we will show, the ratio of total loans to total deposits, representing the financial leverage decision of the financial sector, becomes the key variable for elucidating the coexistence of the above movements and the relevance of the credit channel in the transmission mechanism. In this regard, Fig. 2, which is an extension of von Peter (2005), represents the outlined interrelationships between debt-deflation channels (black), monetary policy tools (blue), and financial leverage (green).

In this research, we design a monetary general equilibrium model that clarifies the interaction between the debt-deflation channels and the ECB instruments described in Fig. 2, and which makes the role played by financial decisions in the transmission mechanism explicit. More specifically, we propose a general equilibrium model within the philosophy of the limited participation models (Christiano and Eichenbaum, 1992; Fuerst, 1992; Gutiérrez, 2006), which provide a sound theoretical foundation to consider the wide variety of financial, monetary, and real issues commented here without detracting from the competitive framework adequate for the Eurozone. In particular, our model can satisfactorily explain the monetary policy’s nominal and real effects and allows the ideas and intuitions mentioned above to be consistently incorporated. In addition, as a key theoretical result, the proposed model originates long-run relationships between inflation and those variables directly controlled by the ECB through the transmission mechanism, also assigning a paramount role to the bank lending channel. In this respect, it consistently describes the underlying monetary transmission mechanism: Considering the explicit objective of the ECB, the explanation of the transmission mechanism must consider inflation, interest rates, and the volume of bank loans as endogenous variables linked by long-run steady relationships, which, as we show, are a theoretical result of our model. Concerning the debt-deflation elements that took place in an environment of expansionary monetary policy, our model contemplates the possibility of money supply increases coexisting with endogenous descents in the total volume of loans and, subsequently, in aggregate demand.

Our contribution is also empirical. As explained above, we develop a VEC model to complement our theoretical analysis and evaluate its predictions for the Eurozone. This complementarity is manifold. First, the implemented VEC model corroborates our

main theoretical results, namely the presence of the predicted long-run relationships enabling the ECB monetary policy, the role played by the financial sector decisions in the transmission mechanism, and the existence of debt-deflation elements inherent to the dynamics. Given that the monetary policy measures affect the economy according to the ECB target, these steady relationships constitute an essential theoretical determinant of the long-run dynamics, a question clarified by the implemented VEC model. The estimated impulse response functions (IRFs) also confirm the presence of debt-deflation links in the short run, initiated by deleverage shocks. Furthermore, considering the difficulty inherent to the class of general equilibrium model employed here in clarifying the short-run dynamics from the pure theoretical perspective, our VEC analysis provides an additional valuable complementarity. As is well known (see, for instance, Fernández-Villaverde et al., 2016), the short-run dynamics, although convergent to that determined by the steady-state relationships, respond to additional specific factors and have a more complex nature. Regarding this issue, jointly with elucidating the role played by the long-run adjustment to the steady-state determined by the ECB monetary policy measures, our VEC model constitutes a useful benchmark for identifying the specific elements that affect the short-run dynamics and for quantifying their contributions. More specifically, the IRFs allow a theoretical interpretation of the channels and relationships working in the short-run, an issue of particular interest in the Eurozone given the presence of an environment characterized by a wide range of monetary, fiscal, macroprudential, and financial measures and shocks with potential short-run effects.

The rest of this paper is divided into four sections. Section “Theoretical description of the economy” describes the economy, defines the equilibrium, states the equivalent social planner’s problem, deduces the long-run mechanisms enabling the ECB monetary policy and their properties and provides the theoretical basis to design an appropriate VEC model. This VEC model is defined and applied in the section “Empirical analysis: a vector error correction model” to empirically analyze the dynamic links between real, monetary, and financial variables in the Eurozone. Lastly, the section “Conclusions” provides some concluding commentaries on the findings.

### Theoretical description of the economy

**The model.** Within the philosophy of the limited participation models in Fuerst (1992) and Christiano and Eichenbaum (1992), the present model extends the structure and ideas in Gutiérrez (2006) and Gutiérrez and Palmero (2013). As explained above, limited participation models have already satisfactorily answered some of the questions under analysis without detracting from the framework of a competitive economy, a reasonable assumption for the Eurozone. On this basis, we assign a central role to the ratio of total loans to total deposits in the economy’s financial sector. The reasons are manifold. On the one hand, in a general equilibrium economy where the monetary policy operates through a financial intermediary, the leverage ratio is a natural candidate to explain how the bank lending channel operates. On the other hand, this ratio captures the reduction of the loans issued by financial institutions, which later causes declines in aggregate investment and demand. Finally, the leverage ratio allows the relevant linkages between the transmission mechanism, financial ratios, and balance sheets to be consistently integrated, an important question in the literature widely analyzed, among others by den Haan et al. (2007), Adrian and Shin (2008), Schularick and Taylor (2012), Claessens et al. (2012), Gambetti and Musso (2017), Bonci and Columba (2008), and Keister and McAndrews (2009). Indeed, since financial sector loans are debts

of firms, this ratio reflects both the balance sheets of banks and firms. As we show in this section, we can interpret the leverage ratio as the fixed-assets-to-total-assets ratio of households, a measure of the financial leverage degree of households, who are the ultimate owners of the economy. For this reason, loan-to-deposit ratio, financial leverage, and leverage ratio are terms used interchangeably in the rest of the paper.

More specifically, and for our purposes, this loans-to-deposits leverage ratio allows us to make two prominent extensions in the model. The first is the detailed microeconomic incorporation of the financial decisions of households and firms, and the subsequent specifications of both the intermediation role played by banks and the way the economy is affected by ECB instruments. Within this context, this ratio details and disentangles the underlying links between inflation, monetary policy instruments, and transmission channels. The second extension arises from the endogenous nature of inflation, interest rates, and the volume of bank loans. In our model, these variables become linked by long-run steady relationships where simultaneous increases in money supply, decreases in real interest rates, deflation, and aggregate demand descents are possible, offering an explanation of the observed debt–deflation mechanisms.

The theoretical description of the economy is simple. There are four agents in the economy: households, financial intermediaries, firms, and a central bank. Households employ their wealth to consume and save. Firms provide final goods to the households, obtaining labor services from the households and capital services from the financial intermediaries. Financial intermediaries channel funds from households to production firms and own all capital in the economy. This is a reasonable approximation since, in the EU, bank loans traditionally finance most investments. The central bank compels the financial intermediaries to hold a percentage of the households' deposits as reserves and carries out the monetary policy by controlling interest rates and money supply. In this respect, it is assumed that the financial sector is the intermediary means by which the monetary policy is conducted. Finally, markets are competitive.

Money is introduced in the sense of Clower (1967). Following Lucas (1980, 1982), trading is divided into different sessions. In the first session, immediately before each period  $t$ , labor and asset markets for the period  $t$  open and close. Subsequently and immediately after each period  $t$ , each household receives the payment for the previous period's labor services from the production sector. Households also receive the savings accumulated during the previous period plus their returns from the financial intermediaries. The central bank takes monetary policy measures, and households and firms carry out buying and selling activities for consumption and capital goods. As in Lucas (1990), it is assumed that households purchase goods and financial assets using their initial money balances.

Households' behavior can be described through a representative consumer. In particular, the per-capita demands for consumption goods, assets, and money, and the labor and capital supplies, are given by the following problem:

$$\begin{aligned}
 & \max_{C_t, l_t^S, D_{t+1}^S, M_t^D} \sum_{t=0}^{\infty} \beta^t \mathcal{U}(C_t, \bar{h} - l_t^S) \\
 & \text{s.t.} \quad p_t C_t + D_{t+1}^S \leq M_t^D, \\
 & M_{t+1}^D \leq p_t w_t l_t^S + D_t^S(1 + i_t) + [M_t^D - p_t C_t - D_{t+1}^S], \\
 & \sum_{t=0}^{\infty} \frac{p_t}{\prod_{j=0}^t (1+i_j)} C_t \geq \sum_{t=0}^{\infty} \frac{p_t w_t}{\prod_{j=0}^t (1+i_j)} l_t^S + D_0^S, \\
 & C_t, l_t^S, \bar{h} - l_t^S, D_t^S, M_t^D \geq 0, \\
 & t = 0, 1, \dots, \infty, \quad D_0^S, M_0^D \text{ historically given.}
 \end{aligned} \tag{1}$$

where  $\beta, t, \mathcal{U}, C_t, \bar{h}$ , and  $l_t^S$  are, respectively, the time discount factor, the period of time, the Bernoulli utility function, the consumption at period  $t$ , the time endowment, and the labor supply at period  $t$ . The first constraint represents the cash-in-advance constraint that applies in the goods and assets markets at period  $t$ , where  $p_t, C_t, D_{t+1}^S$ , and  $M_t^D$  are, respectively, the price of the consumption good at period  $t$ , the consumption of goods at period  $t$ , the amount of money devoted to buying assets at the end of period  $t$ —i.e., the supply of deposits—and the holding of money at the beginning of period  $t$ —i.e., the demand of money. The timing of decisions relevant to the correct interpretation of how money demand is formulated is the following. At each period  $t$ , households use the money obtained at the beginning of the period to buy *along this entire period* consumption goods ( $C_t$ ) and decide *at the end of the period and once they have determined consumption* how much money to devote for bank deposits ( $D^S$ ), which therefore measures the amount of money saved over the period. This supply of bank deposits at period  $t$  is also a demand/purchase of assets against the financial intermediaries, yielding interest in the following period  $t + 1$ . This variable  $D$  is, by its nature, a variable playing a double role as a source of expenditure in one period and of income in the following, therefore appearing in the budget constraints of both periods  $t$  and  $t + 1$ . The assigned time index must be unique, and by convention in monetary general equilibrium models such as ours, the time index refers to the period at which the asset is a source of wealth  $t + 1$  (see, for instance, Gutiérrez, 2006; Heer and Maussner, 2005; Hodrick et al. 1991, or Ljungqvist and Sargent, 2018). Accordingly, in our cash-in-advance *in everything* model,  $D_{t+1}^S$  must be understood as the amount of money that at period  $t$  is used by households to buy assets/deposits, that is, as a component of the demand of money at period  $t$ . To clarify the double dimension of  $D_{t+1}$  as a demand/purchase of assets and a supply/offer of deposits, we incorporate the superscript  $S$ .

The second constraint states that the holding of money at period  $t + 1$  is given by the labor and deposits remunerations plus the amount of money unspent at period  $t$ . As usual,  $w_t$  and  $i_t$  denote the real wage and the nominal interest paid to deposits. The third constraint captures the non-existence of the money illusion: in order to accept exchanges based on money and the described timing scheme, each household requires that, in the whole time horizon, the total discounted nominal value of its consumption should not be lower than the total discounted nominal value of their wealth.

In the first session of period  $t$ , the financial sector demands (through the sale of assets) the amount  $D_t^D$  of deposits from the households, and the central bank takes the monetary policy measures fixing the legal reserves coefficient  $s_t$ , the money supply change  $G_t$ , and implementing the control of interest rates. To simplify notation, we anticipate that, at the financial equilibrium,  $D_t^S = D_t^D = D_t$ . As a consequence, the financial sector keeps  $s_t D_t$  as reserves in the central bank, so this amount is unavailable for productive capital—i.e., production firms cannot borrow it—but, at the same time, the money supply changes  $G_t$  is added to the quantity of resources available for supplying productive capital—i.e., the amount that production firms can borrow. Therefore, the financial sector can supply productive capital up to a value  $(1 - s_t) D_t + \rho_t G_t$ , where  $\rho_t$  is the percentage of the money supply change which becomes productive capital and accumulates the difference for the next period. Since this accumulated fraction of the deposits constitutes a resource accumulated during period  $t - 1$  for the (next) period  $t$ , and it aims to eliminate bankruptcy risks, it will be considered as a demand for financial capital goods. At the first session of period  $t$ , denoting the per-capita household's deposits in real terms<sup>5</sup> by  $d_t, d_t = \frac{D_t}{p_{t-1}}$ , the productive capital by

$K_t^P$ , and the financial capital by  $K_t^F$ , and assuming that the central bank formulates the increases in the money supply  $G_t$  as a percentage  $g_t$  of the amount of deposits  $D_t$  -i.e.,  $G_t = g_t D_t$ -, then

$$K_t^P \leq \frac{(1-s_t)D_t + \rho_t G_t}{p_{t-1}} = \frac{(1-s_t)D_t + \rho_t g_t D_t}{p_{t-1}} = (1 - s_t + \rho_t g_t) d_t,$$

$$K_t^F = \frac{D_t}{p_{t-1}} - K_t^P = d_t - K_t^P = (s_t - \rho_t g_t) d_t.$$

At period  $t$ , the financial sector owns all the capital factors in the economy  $K_t^P + K_t^F$ , provides capital services to the production firms, and must return the deposits plus their interest to the households. Strictly speaking, the financial sector decides the supply of productive capital, that is, the quantity of productive capital to be lent to the production sector, and the production sector decides the demand for productive capital, i.e., the amount of capital to be borrowed from the financial sector, and therefore also the demand of financial capital. In equilibrium, demand equals supply, and to simplify notation, we consider  $K_t^P$  as both demand and supply of productive capital. Then, in per-capita terms, the problem solved by this financial sector is

$$\max_{K_t^P, K_t^F, D_t^D} \Pi_t = p_t (K_t^P + K_t^F) (1 - \delta) + p_t K_t^P r_t^P - D_t^D (1 + i_t)$$

$$\text{s.t. } p_{t-1} K_t^P \leq (1 - s_t + \rho_t g_t) D_t^D, \tag{2}$$

$$p_{t-1} K_t^F = D_t^D - p_{t-1} K_t^P,$$

where  $\Pi_t$  are the financial sector profits,  $r_t^P$  is the rental price of capital paid by production firms to financial firms, and  $\delta$  is the depreciation rate, defined on the total capital<sup>6</sup> ( $K_t^P + K_t^F$ ). The consideration of the market structure of the financial sector is in our model of particular interest. On the one hand, the market structure is an important causal factor of the sector profits. On the other, due to the trade-offs between competition and financial stability, it implies an optimum that must be carefully determined by the policymakers, especially in periods of crisis such as the GFC here considered: Effective competition translates into lower bank's interest margins and higher social welfare, but it can also imply higher financial fragility and instability leading to bankruptcies, also prejudicial in terms of social welfare (see for instance Allen and Gale, 2004; Benchimol and Bozou, 2022; Jiménez et al., 2010). In addition and as the empirical analysis by Kim (2018) concludes, this trade-off seems to be dependent on the bank size, being particularly present for small banks. In this respect, the battery of measures implemented by the ECB and the European Commission promoting controlled and supervised bank mergers and safeguarding internal competition (see Koopman, 2011), appears as the most effective policy to ensure both financial stability and social welfare. We refer the interested reader to Benchimol and Bozou (2022), where these questions are theoretically and quantitatively analyzed. Regarding the market structure of the Eurozone financial sector, the empirical analyses of the usual market power indexes suggest that, as a result of the continuous and deep harmonizing and macroprudential policies, the financial sector structure is oligopolistic but not too far from perfect competition (see Căpraru et al. 2020; Cruz-García et al. 2017). Assuming that markets are competitive, the number of financial intermediaries adjusts until the condition of zero profits is verified, and then

$$p_t (K_t^P + K_t^F) (1 - \delta) + p_t K_t^P r_t^P = D_t^D (1 + i_t), \tag{3}$$

where  $p_{t-1} K_t^P = (1 - s_t + \rho_t g_t) D_t$  and  $p_{t-1} K_t^F = D_t - p_{t-1} K_t^P$ , since the first constraint in problem (2) always binds if prices are positive. As shown in Appendix A of the supplementary section, if we define the real interest rate paid by financial intermediaries to household deposits by  $r_t^H - \delta$ , this zero profits

condition can also take the form of

$$(1 - s_t + \rho_t g_t) r_t^P - r_t^H = 0. \tag{4}$$

This zero profits equilibrium condition deserves a deeper examination. First, as shown in Appendix A, it implies that the interest rate charged by banks to firms,  $r_t^P$ , must necessarily be higher than the interest rate banks pay to deposits,  $r_t^H - \delta$ . In this respect, it is worth noting that, in standard monetary general equilibrium models including a financial sector, this interest rate spread emerges either as a mark-up stemming from the monopolistic competition financial market structure, as in Bernanke and Gertler (1995), or because of the consideration of a non-zero private sector's default probability, as in Corsetti et al. (2013). In our model, since the official reserves requirement aims to remove default risks, the interest rate spread is a natural consequence of the competitive economy that internalizes financial risk and implements the above-quoted instrument to remove the risk of bank default. Jointly with this interesting theoretical result, condition (4) clarifies the role played by the ECB standing facilities. As is well known, the ECB controls interest rates, mainly by fixing the rates on the deposit facility and the marginal lending facility<sup>7</sup>. The deposit rate establishes the floor on the market interest rate for bank loans since no bank will lend money out at less than what it can earn at the deposit facility in the ECB. The lending rate constitutes the ceiling on the market interest rates, given that this rate is the cost at which any bank can obtain liquidity from the ECB. Using these standing facilities, the ECB controls the money market interest rates within a corridor, whose range, denoted by  $Q_b$ , plays a crucial role. First, concerning the interest rate paid to the household's deposits,  $r_t^H - \delta$ , and the interest rate perceived by the financial sector,  $r_t^P$ , the control of interest rates by the central bank in our competitive economy results in a margin for  $r_t^H$  concerning  $r_t^P$  given by  $r_t^P - r_t^H = Q_t + \delta = m_t$ . Second, this margin also has consequences for the variable  $\rho$ , the percentage of the money supply change that becomes productive capital. Indeed, although the variable  $\rho$  is not included in condition (3), its value is determined by the (equivalent) zero profits condition (4):

$$(1 - s_t + \rho_t g_t) r_t^P - r_t^H = 0,$$

$$\rho_t = \frac{1}{g_t} \left[ \frac{r_t^H}{r_t^P} - 1 + s_t \right] = \frac{1}{g_t} \left[ \frac{r_t^P - m_t}{r_t^P} - 1 + s_t \right] = \frac{1}{g_t} \left[ \frac{m_t}{r_t^P} + s_t \right].$$

In economic terms, once the central bank decides  $s_t$  and  $g_t$  and fixes the differential  $m_t$  between perceived and paid interest rates, the zero profits condition determines  $\rho_t$ . As explained before,  $\rho$  is the percentage of the money supply change lent to the production firms. Therefore, it is logical to find that  $\rho_t$  depends on the number of financial firms, which in turn is a consequence of the verification of the zero profits condition, which, at the same time, depends on each established margin  $m_t$ . This implies that  $\rho_t$  is an endogenous variable whose equilibrium value is jointly determined with the model's remaining endogenous variables. We clarify these aspects in Appendix A of the supplementary information.

Production is given by the function  $y_t = F(K_t^P, l_t) = (K_t^P)^\alpha l_t^{1-\alpha}$ . This function governs the production of the unique good of the economy, which can be used as a consumption good  $C_t$ , productive capital good  $K_{t+1}^P$  (that allows the productive activity of firms), or financial capital good  $K_{t+1}^F$  (that allows bankruptcy risk to be removed). Given our assumptions, the problem solved by the production sector is, in per-capita terms:

$$\max_{K_t^P, l_t} p_t (K_t^P)^\alpha l_t^{1-\alpha} - p_t r_t^P K_t^P - p_t w_t l_t^D, \tag{5}$$

where we have already considered that, at equilibrium, the

demand for productive capital of the production sector equals the supply provided by the financial sector.

Regarding the money market, and since all constraints in the household's problem become binding (see Appendix A of the supplementary information), the money demand at period  $t$ ,  $M_t^D$ , is given by the expression  $M_t^D = p_t C_t + D_{t+1}$ . As explained before, the demand for money is composed of the amount of money used to buy consumption goods along the period,  $p_t C_t$ , plus the amount of money saved that period and devoted to making bank deposits,  $D_{t+1}$ . Given the intertemporal nature of this saving variable, the time index assigned by convention is the period at which they yield returns, period  $t + 1$ . However, since this is the amount of money demanded to make bank deposits at period  $t$ , the price level to be considered in order to formulate this demand of money in real terms is  $p_t$ :

$$\frac{M_t^D}{p_t} = \frac{p_t C_t + D_{t+1}}{p_t} = C_t + \frac{D_{t+1}}{p_t} = C_t + d_{t+1}.$$

The money supply,  $M_t^S$ , fixed by the central bank but also determined by the financial sector, is given by  $M_t^S = \rho_0 M_0 + \sum_{j=0}^t \rho_j G_j$ , where  $M_0$  and  $G_t$  are decided by the Central Bank. The money market clearing condition is therefore

$$M_t^S = \rho_0 M_0 + \sum_{j=0}^t \rho_j G_j = p_t [C_t + d_{t+1}] = M_t^D.$$

We can now define the competitive general equilibrium for this economy. As usual, this equilibrium is defined as the *sequences of prices and decisions such that: each agent solves its problem, taking as given the variables out of its control; profits are zero; and markets clear*. The formulation of this equilibrium is somewhat burdensome. However, we can simplify by following the line of reasoning presented in Cooley and Prescott (1995) and Heer and Maussner (2005) and applied by Gutiérrez (2006) and Gutiérrez and Palmero (2013) in a parallel limited participation model. Indeed, as shown in detail in Appendix A of the supplementary material, it is possible to formulate the equilibrium in real terms as the solution to the following equivalent Social Planner's Problem:

**Definition 1.** (Equivalent social planner's problem formulation) In real terms, the equilibrium of the Economy is given by the sequences  $\{\hat{y}_t\}_{t=0}^\infty$ ,  $\{\hat{C}_t\}_{t=0}^\infty$ ,  $\{\hat{l}_t\}_{t=0}^\infty$  and  $\{\hat{d}_t\}_{t=0}^\infty$  such that:

- Given  $\{\hat{y}_t\}_{t=0}^\infty$ , the sequences  $\{\hat{\rho}_t\}_{t=0}^\infty$ ,  $\{\hat{C}_t\}_{t=0}^\infty$ ,  $\{\hat{l}_t\}_{t=0}^\infty$  and  $\{\hat{d}_t\}_{t=0}^\infty$  solve the Social Planner's problem

$$\begin{aligned} & \max_{C_t, l_t, d_{t+1}} \sum_{t=0}^\infty \beta^t \mathcal{U}(C_t) \\ & \text{s.t.} \quad C_t + d_{t+1} \leq [\hat{y}_t d_t]^\alpha (l_t)^{1-\alpha} + d_t(1 - \delta), \\ & \quad 0 \leq l_t \leq \bar{h}, \\ & \quad C_t, d_{t+1} \geq 0, \\ & \quad t = 0, 1, \dots, \infty, \quad d_0 \text{ historically given.} \end{aligned} \tag{6}$$

- The sequence  $\{\hat{y}_t\}_{t=0}^\infty$  verifies

$$\hat{y}_t = 1 - \frac{m_t}{\alpha(\hat{y}_t \hat{d}_t)^{\alpha-1}} \quad \forall t. \tag{7}$$

We thus count on a simple formulation to study the monetary general equilibrium as well as the real and nominal effects caused by monetary policies and changes in the leveraging policy of firms. The sequences  $\{\hat{C}_t\}_{t=0}^\infty$ ,  $\{\hat{l}_t\}_{t=0}^\infty$  and  $\{\hat{d}_t\}_{t=0}^\infty$  provided by the social planner's problem coincide with those in the monetary general equilibrium. Regarding all the other variables in the

monetary general equilibrium, and as explained in Appendix A of the supplementary information, they can be obtained from the equivalent social planner's problem by applying the following relationships:

$$\begin{aligned} \hat{K}_t^P &= \hat{y}_t \hat{d}_t, & \hat{K}_t^F &= \hat{d}_t(1 - \hat{y}_t), \\ \hat{\rho}_t &= \frac{\hat{y}_t + s_t - 1}{g_t}, & \hat{p}_t &= \frac{\hat{\rho}_0 M_0 + \sum_{j=0}^t \hat{\rho}_j G_j}{C_t + d_{t+1}}, \\ \hat{w}_t &= (1 - \alpha)(\hat{y}_t \hat{d}_t)^{\alpha-1} l_t^{1-\alpha}, & \hat{r}_t^P &= \alpha(\hat{y}_t \hat{d}_t)^{\alpha-1} l_t^{1-\alpha}, & \hat{i}_t &= (1 + \hat{y}_t \hat{r}_t^P - \delta) \frac{\hat{p}_t}{\hat{p}_{t-1}} - 1. \end{aligned}$$

**The role of the loan-to-deposit ratio.** This social planner's problem formulation constitutes an operative and manageable framework to study the monetary general equilibrium. For our purposes, one of its virtues is the incorporation of the loan-to-deposit ratio as a key variable in explaining the economic dynamics. From the mathematical point of view, this is done through the introduction of the social planner's problem formulation of a new variable,  $\gamma$ . As we show in Appendix A of the supplementary section, this new variable, defined as

$$\gamma_t = (1 - s_t + \rho_t g_t),$$

has an immediate interpretation in monetary, financial, and economic terms, being equivalent to the loan-to-deposit ratio of the financial sector. Since

$$K_t^P = (1 - s_t + \rho_t g_t) d_t = \gamma_t d_t,$$

and we are assuming that firms acquire all their productive capital by borrowing it from financial intermediaries, the total amount of loans in our economy coincides with the productive capital  $K_t^P$ , and therefore

$$\text{Loan-to-Deposit Ratio}_t = \frac{K_t^P}{d_t} = \frac{(1 - s_t + \rho_t g_t) d_t}{d_t} = (1 - s_t + \rho_t g_t) = \gamma_t.$$

Therefore, decreases in  $\gamma_t$  respond to relative descents in productive capital, financial sector loans, and productive firms' total debt, all ultimately constituting a financial deleveraging process. Given that financial leverage is defined as the use of borrowed money to obtain production and profits, and since all productive capital is financed by bank loans, lower values of  $\gamma_t$  imply the presence of a financial deleveraging process for the whole economy. Alternatively, as  $K_t^P$  takes the form of physical capital,  $\gamma_t$  is the *fixed-assets-to-total-assets ratio* from the position of households, that is, their operating leverage. In our general equilibrium model, households are the ultimate owners of the economy, so business risk and financial risk coincide (see, for instance, Brealey et al., 2014), and  $\gamma$  can be understood both as the operating and the financial leverage degree of the economy as a whole. For interpretations and analyses of this and similar financial leverage ratios, we refer the interested reader to ECB European Central Bank (2012), Schularick and Taylor (2012), or Mendoza and Terrones (2014).

Through this new variable  $\gamma_t$ , we can consider and study not only the consequences of monetary policies changing the reserves coefficient  $s_t$  and the money supply  $g_t$ , but also the effects of modifications in structural characteristics idiosyncratic to the financial intermediary sector, captured by the parameter  $\rho_t$ . Our proposal, therefore, constitutes an interesting option to analyze and theoretically explain the observed links between credit, monetary policy, inflation/deflation, debt, leverage, financial cycles, and real cycles identified by the empirical literature mentioned in this manuscript. Indeed, as shown in the following subsection, this *total loans-to-total deposits* ratio  $\gamma_t$  appears as the key variable in the monetary transmission mechanism, governing the real and nominal effects of the ECB policy measures on all the variables in the economy.

**Loan-to-deposit ratio, transmission mechanism, and debt-deflation process.** Let us now consider one of our central hypotheses, namely the existence of stable inflation targeting for the ECB and then of long-run relationships between the variables controlled by the ECB and involved in the transmission mechanism, and inflation. If we solve the social planner's problem (6), we reach the following first-order necessary and sufficient conditions:

$$\frac{U'(C_t)}{U'(C_{t+1})} = \beta[\alpha\gamma^{t+1}d_{t+1}^{\alpha-1} + 1 - \delta],$$

$$C_t + d_{t+1} = [\gamma_t d_t]^\alpha (l_t)^{1-\alpha} + d_t(1 - \delta).$$

Since this model represents the detrended dynamics, let us look for a long-run steady-state in which the margin  $m_t$  charged by the financial sector, the legal reserves coefficient  $s_t$ , and the changes in money supply expressed as a percentage of nominal deposits  $g_t$ , are constant. Let these steady-state values be  $m, s$ , and  $g$ . As we prove below, this steady state exists, and all the variables remain constant with the only exception of prices  $p_t$  and the money supply increases  $G_t$ .

To see this, let us consider condition (7) of the social planner's problem formulation. In the steady state, the deposits in real terms must be constant, and as  $m_t$  and  $d_t$  are constant, so is  $\gamma_t$ . Then, from the first order necessary condition, at this steady-state

$$1 = \beta[\alpha\gamma^\alpha d^{\alpha-1} + 1 - \delta], \quad d = \left[ \frac{\alpha\beta\gamma^\alpha}{\delta\beta + 1 - \beta} \right]^{\frac{1}{1-\alpha}}.$$

From this expression, we obtain that the per-capita deposits in real terms  $d$  positively depend on the parameter  $\gamma$ . Analogously, from the second first-order condition, the steady-state value for the per-capita consumption is given by

$$C = \gamma^\alpha d^\alpha - d\delta,$$

which, we can show after some algebra, positively depends on the parameter  $\gamma$ .

In this detrended steady state, the aggregate per-capita capital stock is constant and given by

$$K^P = (1 - s + \rho g)d = \gamma d.$$

Denoting with  $I$  the detrended per-capita real investment, by definition that replacing depreciation, we arrive at  $I = \delta K^P = \delta\gamma d$ , which also positively depends on the parameter  $\gamma$ .

In our model and as shown in Appendix A of the supplementary information,  $\hat{l}_t = \bar{l}$ . Taking  $\bar{h} = 1$ ,

$$\gamma = (K^P)^\alpha = (\gamma d)^\alpha,$$

and therefore the steady-state values of the rental price of capital  $r^P$  and of the real wage  $w$  are

$$r^P = \frac{\partial y}{\partial K^P} = \frac{\partial (K^P)^\alpha}{\partial K^P} = \alpha(K^P)^{\alpha-1} = \alpha(\gamma d)^{\alpha-1} = \frac{\alpha}{(\gamma d)^{1-\alpha}},$$

$$w = \frac{\partial y}{\partial l} = \frac{\partial (K^P)^\alpha l^{1-\alpha}}{\partial l} = (1 - \alpha)(K^P)^\alpha l^{-\alpha} = (1 - \alpha)(\gamma d)^\alpha.$$

This implies that the real interest rate  $r^P$  negatively depends on the ratio  $\gamma$ , this dependence being positive for the real wage.

Regarding  $\rho$  and according to its definition, its steady-state value is

$$\rho = \frac{\gamma + s - 1}{g},$$

which positively depends on the loan-to-deposit ratio  $\gamma$ . Let us now study inflation in this model, denoted by  $\pi_t$ . Since the price level is given by

$$\hat{p}_t = \frac{\hat{\rho}_0 M_0 + \sum_{j=0}^t \hat{\rho}_j G_j}{\hat{C}_t + \hat{d}_{t+1}},$$

we get that, at the steady-state where  $\rho_t, \hat{C}_t$  and  $\hat{d}_t$  are constant,

$$(1 + \pi_t) = \frac{\hat{p}_t}{\hat{p}_{t-1}} = \frac{M_0 + \sum_{j=0}^t G_j}{M_0 + \sum_{j=0}^{t-1} G_j} = 1 + \frac{G_t}{M_{t-1}}.$$

Therefore, at the assumed steady-state,

$$G_t = \pi_t M_{t-1}, \quad \pi_t = \frac{G_t}{M_{t-1}},$$

a result consistent with empirical results and theoretical analyses. In our steady-state  $G_t = g_t \hat{d}_t \hat{p}_{t-1} = g d \hat{p}_{t-1}$ , and from the former equation we obtain

$$\pi_t = \frac{gd}{M_{t-1} \hat{p}_{t-1}}.$$

According to our expression for  $\hat{p}_{t-1}$ , at the steady-state

$$\hat{p}_{t-1} = \frac{\rho M_{t-1}}{C + d}, \quad \frac{\hat{p}_{t-1}}{M_{t-1}} = \frac{\rho}{C + d} = \text{constant},$$

and, consequently, the inflation rate at the steady state is also constant and given by

$$\pi = \frac{gd\rho}{C + d}.$$

Summing up, we have shown that if the central bank fixes a constant legal reserves coefficient  $s$ , a constant percentage of nominal deposits  $g$  to formulate the money supply changes and a constant margin  $m$  to establish the interest rate paid to household deposits, then there exists a steady-state implying constant values for all variables in the monetary general equilibrium except for prices  $p_t$  and the money supply increases  $G_t$ . In addition, there exists a constant steady-state value for inflation, which is endogenously determined and that, as with the values of all the other endogenous variables, depends on the loan-to-deposit ratio of the financial sector.

The dependence of all these steady-state values on  $\gamma$  can also be analyzed after substituting  $d$  for its steady-state expression. Since we are specifically interested in the hypothesized existence of long-run steady links between the variables in the interest rate channel, bank lending channel, and inflation, we focus on the expressions for the interest rate and inflation. After substituting  $d$  for its steady-state expression, we obtain

$$r^P = \frac{\delta\beta + 1 - \beta}{\gamma\beta}, \tag{8}$$

which implies a negative relationship between the real interest rate and the loan-to-deposit ratio, and

$$\pi = \frac{\alpha\beta(\gamma + s - 1)}{(1 - \delta)(1 - \beta) + 1}, \tag{9}$$

which indicates a positive relation of inflation  $\pi$  to  $\gamma$ . Thus, from our steady-state expressions, we conclude that in the long run, there exist two equations linking these three variables, a finding consistent with the inflation objective of the ECB and the presence of an interest channel and a bank lending channel as transmission mechanisms, and justifying the implementation of a VEC model to analyze the empirical data consistently.

On this point, it is worth noting two questions. First, from Eqs. (8) and (9), the influence of interest rates and bank loans on prices, the so-called interest channel and bank lending channel, are exerted through the leverage ratio  $\gamma$ . Indeed, this variable  $\gamma$  enters as a fundamental in all the functions explaining the steady-state values. Since this ratio  $\gamma$  is given by the expressions

$$\gamma_t = (1 - s_t + \rho_t g_t), \quad \gamma_t = 1 - \frac{m_t}{\alpha(\gamma_t d_t)^{\alpha-1}},$$



that depend on the reserves coefficient  $s_t$ , the range  $m_t$  of the corridor established by the standing facilities, and the money supply changes  $g_t$ , the variable  $\gamma_t$  is ultimately responsible for the monetary transmission mechanism. Second, these long-run relationships in Eqs. (8) and (9) also agree with the presence of debt–deflation processes observed by several researchers in the Eurozone during the crisis. For our purposes and as commented on in the first section, it is interesting to remark that the debt–deflation theory implies a negative relationship between the real interest rate and the loan-to-deposit ratio, a positive dependence of inflation on  $\gamma$ , and a negative relationship between inflation and the real interest rate, such as those identified by our long-run theoretical expressions linking  $\pi$ ,  $\gamma$  and  $r^P$ . Therefore, expressions (8) and (9) summarize the links between debt–deflation channels, monetary policy instruments, and financial leverage depicted in Fig. 2.

It is worth noting the consistency of our model with the mechanisms and effects constituting the empirical and theoretical foundations of monetary theory. In particular, if we consider a temporary increase in money supply, the above equations describing the steady-state directly lead to the existence of a short-run positive correlation between money and output and to the appearance of a permanent increase in the price level. More specifically, since the increase in  $g_t$  is temporary, there are no changes in the steady-state values; however, this temporary increment in  $\gamma_t = (1 - s_t + \rho g_t)$  causes temporary increases in inflation, and in real output, capital and consumption. All these variables return to their original steady-state values, including the inflation rate. Thus the temporary increase in inflation is accompanied by a permanent increase in the price level as predicted by the quantitative theory of money, as well as by short-run real effects. The formal reasonings are those explained in Gutiérrez (2006) for a simpler model.

### Empirical analysis: a vector error correction model

Our limited participation model can be envisaged as a stylized monetary general equilibrium model consistent with the presence of a monetary transmission mechanism implying debt–deflation dynamics. As shown above, it predicts a positive relationship between the loan-to-deposit ratio and inflation, a negative relationship between leverage and real interest rates, and a negative relationship between real interest rates and inflation. According to the data and as Fig. 3 depicts, all these correlations were present in the EU during the GFC, suggesting the existence of a debt–deflationary feedback loop in the EU during this period as the one described in the theoretical model. This observation justifies a deeper analysis of the relationships set out in the previous sections.

In this respect, the empirical analyses based on VEC modeling are capable of both a long-run and a short-run investigation of the interdependencies between the included variables and their dynamics. In VEC models, the adjustment to the long-run relationships, jointly with other elements particular to the short run, determines the dynamics of the variables involved. As previously concluded, this is just the framework suggested by our limited participation model, since we have deduced the existence of two steady-state equations enabling monetary policy and linking the leverage ratio, inflation rate, and real interest rate. Given that these equations represent long-run equilibrium relationships between the variables, we expect the VEC model to identify the associated cointegration equations. Once cointegration is confirmed, we estimate the VEC model to quantify the role played by the long-run relationships on the dynamic adjustments.

**Data.** Utilizing aggregate data provided by the ECB’s Statistical Data Warehouse, we run the empirical analysis from the onset of the GFC

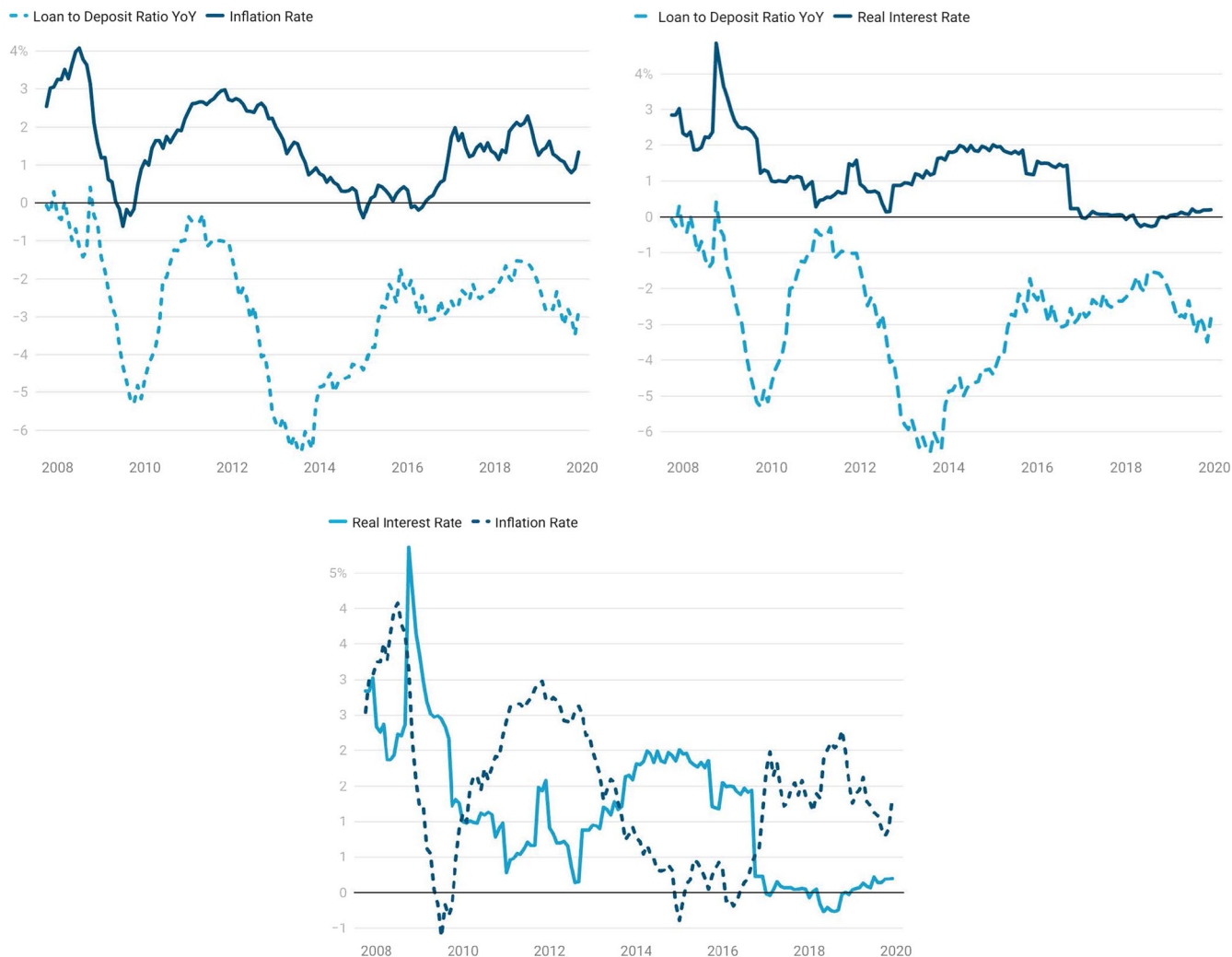
until the first signs of the unfolding COVID-19 pandemic, covering the interval from November 2007 to December 2019. As outlined in the previous section, the considered variables are the price level, the real interest rate, and the aggregate loan-to-deposit ratio. The price level takes the natural logarithm of the core index of the Harmonized Index of Consumer Prices (HICP), which allows us to remove the effects of the highly volatile energy and food prices. It is an appropriate exclusion since these components influence less the aggregate demand financed by loans. We adjust the bank lending rate by the expected inflation to obtain the real interest rate. The bank lending rate is a weighted average of interest rates for households (cost of borrowing for house purchases) and non-financial corporations (loans to non-financial firms with a term over one year). Weighting is done based on loan volumes, and the rate corresponds to a 24-month moving average. For the adjustment, we apply the HICP inflation forecasts based on the ECB Survey of Professional Forecasters (SPF)<sup>8</sup>. The ratio between the private sector aggregate loans and the private sector aggregate deposits represents the private sector’s financial leverage which enters into the model after taking its natural logarithm. The private sector includes non-financial corporations and households and non-profit institutions serving households.

**Cointegration.** Before testing for cointegration, it is necessary to verify that the variables have the same order of integration. Here, the three considered series—log core HICP ( $\pi$ ), loan-to-deposit ratio ( $\gamma$ ), and real interest rate ( $r^P$ )—are tested by the Augmented Dickey–Fuller (ADF) unit root test and the Kwiatkowski et al. (1992) (KPSS) stationarity test.

As Table 1 shows, the log leverage ratio and the real interest rate unequivocally follow an I(1) process. However, the applied tests indicate contradicting results for the log price level when only an intercept is included in the test equations. Yet, considering the statistical evidence on the deterministic trend behavior of the series and the visual inspection of the variables (Appendix B of the supplementary section), we rely on the test results that contain both the intercept and trend. Correspondingly, while the KPSS test still rejects stationarity at a 10 percent significance level, the ADF test rejects the unit root at a 1 percent significance level when taking the first difference of the series. In addition, the stationarity of the first difference log price level is also supported by the analysis of Caporale and Kontonikas (2009), where, despite the contradicting results of the ADF and KPSS tests, stationarity for inflation rates measured as in the present paper is concluded. Consequently, we consider all variables stationary after taking their first difference, which allows us to proceed with the cointegration procedure.

We now investigate potential long-run relationships between the series by applying the Johansen multivariate cointegration test (Johansen, 1988). Before that, a vector autoregressive (VAR) model is fitted to the data to specify the appropriate lag structure by using Lag Order Selection Criteria. Here, we rely on the Akaike information criterion (AIC)<sup>9</sup>, which indicates four lags. As shown by Pesaran et al. (2000) and Ahking (2002), another essential aspect to consider is the deterministic trend specification of the model. Figure S1 in Appendix B of the supplementary information, which plots the three variables, suggests different trending behavior in the series. In such cases, a linear combination of the series removes stochastic but not deterministic components in trends. According to Pesaran et al. (2000) and Juselius (2006), such a condition can be addressed by including a restricted deterministic trend in the cointegration space. Consequently, we estimate the model by imposing *unrestricted intercept* and *restricted linear trend coefficient* in the two cointegration relations.

Table 2 summarizes the output of the applied Johansen cointegration test. The Trace and the Max-Eigenvalue statistics



**Fig. 3 Empirical evidence of debt-deflation links in the Eurozone.** Visual inspection of debt-deflation links: loan-to-deposit ratio and inflation rate (upper-left, positive correlation); loan-to-deposit ratio and real interest rate (upper-right, negative correlation); interest rates and inflation (bottom, negative correlation).

**Table 1 Unit root and stationarity tests.**

Variables	ADF test		KPSS test	
	Intercept	Intercept and trend	Intercept	Intercept and trend
<i>Level</i>				
Log leverage ratio	-0.53120	-2.20840[*]	1.42592***	0.13340*[[***]]
Log HICP	-2.89289**	-2.68521[[**]]	1.42932***	0.31227***[[***]]
Real interest rate	-2.27620	-2.72704	0.75625***	0.13379*[[***]]
<i>First difference</i>				
Log leverage ratio	-3.60016***	-3.57939**	0.12440	0.12284*
Log HICP	-14.56247***	-15.10757***[[***]]	0.52838**	0.12451*[[**]]
Real interest rate	-12.65400***	-12.62636***	0.06035	0.05043

\*, \*\*, \*\*\* Indicates significance, that is, rejection of the null hypothesis on a 10%, 5%, and 1% level, where the null in the case of the ADF test is the presence of a unit root, and in the case of KPSS is stationarity. In brackets, the null hypothesis includes no trend in the series.

indicate two cointegrating vectors. It is worth noting that this outcome confirms the theoretical prediction of the stylized model formulated in the section “Theoretical description of the economy”, which establishes the existence of two long-run steady-state relationships linking  $\pi$ ,  $r^p$ , and  $\gamma$ , crucial in explaining the monetary transmission mechanism and the underlying debt-deflation process.

We also obtain the estimated coefficients for the two cointegration equations from the Johansen test. These estimations are

$$\pi_t = -4.38042 + 0.00102t + 0.03922\gamma_t \tag{10}$$

$$\gamma_t = 0.74243 - 0.00284t - 0.01359r_t^p \tag{11}$$

**Table 2 Johansen cointegration test.**

Hypothesized no. of CE(s)	$r = 0$	$r \leq 1$	$r \leq 2$
Trace	68.64253***	32.45651***	9.57966
Eigenvalue	36.18602***	22.87685**	9.57966

Trace represents the trace test statistics and eigenvalue is the maximal eigenvalue test statistics. \*\*\*, \*\* denote rejection of the null hypothesis at the 1% and 5% significance levels.

**Table 3 Error corrections' (ECTs) coefficients.**

ECTs	$\Delta r^P$	$\Delta \gamma$	$\Delta \pi$
$\eta_{v1}$	11.93467 (10.19110)	-0.30748*** (0.07600)	-0.08093*** (0.02102)
$\mu_{v2}$	-1.71741 (3.18682)	-0.11187*** (0.02387)	0.01233 (0.00657)

Numbers in parentheses are *t*-statistics. \*\*\* denote  $p < 0.01$ .

Concerning the endogenous variables  $\pi$ ,  $r^P$ , and  $\gamma$ , both estimations of the long-run equilibrium equations confirm the co-movements of variables predicted by the stylized model through Eqs. (8) and (9) and appropriately reproduce the theoretical steady-state relations in the VECM system. Therefore, these cointegration equations constitute a significant empirical validation of the presence of debt–deflation mechanisms in the monetary transmission during the post-2008 crisis interval in the Eurozone.

**VEC model specification.** The presence of at least two cointegrating equations justifies using a VECM to analyze the variable dynamics and the role played by these long-run steady-state relationships. We introduce two dummy variables to remove potential disturbances and structural breaks in the data and enhance robustness. One event we take into account is the European sovereign debt crisis, represented by  $D^{dc}$ , which takes the value of 1 for the months between September 2010 and February 2012 and zero otherwise. This interval reflects the elevated long-term interest rate on debt securities denominated in Euro, which profoundly impacted domestic banks' interest rates and, thus, the real interest rate. The other phenomenon we consider is the zero lower bound (ZLB) episode, defined by  $D^{zb}$ . The first month in which the interest rate on the main refinancing operations of the ECB dropped to zero was March 2016. Accordingly,  $D^{zb} = 1$  from this date onward, and zero otherwise. Both dummy variables enter the model as exogenous variables.

According to VEC modeling, the two cointegrating equations imply the existence of two error correction terms (ECTs),

$$\begin{aligned} ECT_t^{v1} &= \pi_t - 0.00102t - 4.38042 - 0.03922\gamma_t, \\ ECT_t^{v2} &= \gamma_t + 0.00284t - 0.74244 + 0.01359r_t^P, \end{aligned}$$

and lead to a VEC model consisting of the following equations:

$$\begin{aligned} \Delta r_t &= \Psi^1 + \sum_{i=1}^3 \alpha_i^1 \Delta r_{t-i}^P + \sum_{i=1}^3 \beta_i^1 \Delta \pi_{t-i} + \sum_{i=1}^3 \lambda_i^1 \Delta \gamma_{t-i} + \eta^1 ECT_{t-1}^{v1} \\ &+ \mu^1 ECT_{t-1}^{v2} + \delta_1^1 D_t^{dc} + \delta_2^1 D_t^{zb} + \varepsilon_t^1, \end{aligned} \tag{12}$$

$$\begin{aligned} \Delta \pi_t &= \Psi^2 + \sum_{i=1}^3 \alpha_i^2 \Delta r_{t-i}^P + \sum_{i=1}^3 \beta_i^2 \Delta \pi_{t-i} + \sum_{i=1}^3 \lambda_i^2 \Delta \gamma_{t-i} + \eta^2 ECT_{t-1}^{v1} \\ &+ \mu^2 ECT_{t-1}^{v2} + \delta_1^2 D_t^{dc} + \delta_2^2 D_t^{zb} + \varepsilon_t^2, \end{aligned} \tag{13}$$

$$\begin{aligned} \Delta \gamma_t &= \Psi^3 + \sum_{i=1}^3 \alpha_i^3 \Delta r_{t-i}^P + \sum_{i=1}^3 \beta_i^3 \Delta \pi_{t-i} + \sum_{i=1}^3 \lambda_i^3 \Delta \gamma_{t-i} + \eta^3 ECT_{t-1}^{v1} \\ &+ \mu^3 ECT_{t-1}^{v2} + \delta_1^3 D_t^{dc} + \delta_2^3 D_t^{zb} + \varepsilon_t^3. \end{aligned} \tag{14}$$

As is well known, significant and negative coefficients for ECTs ( $\eta$ s and  $\mu$ s) indicate a long-run adjustment of each variable toward their steady state. This adjustment, a consequence of the position of the variable relative to the long-run equilibrium

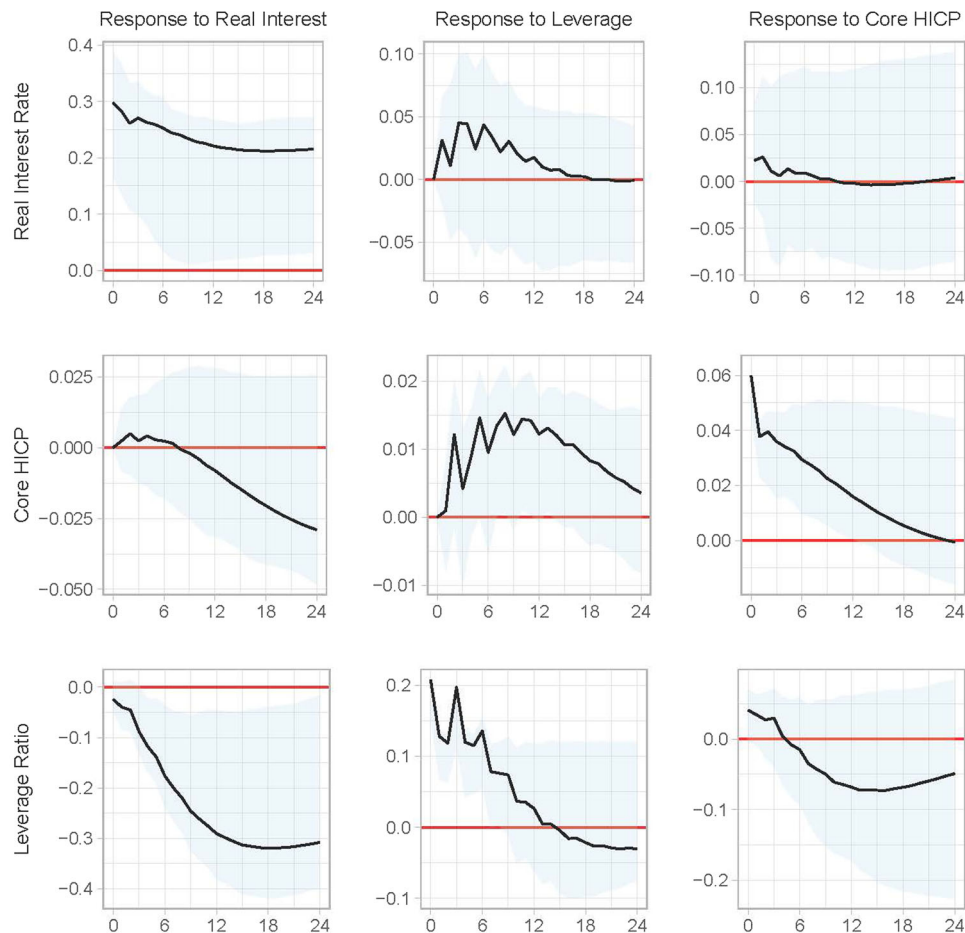
relation, is determined by the combination of the variables included in the given cointegrating equation.

**Long-run dynamics.** Concerning the long-run analysis, the *t*-statistics and the related *p*-values in Table 3 indicate a significant ECT coefficient in  $v_1$  for the price index ( $\eta^2 = -0.08093$ ), suggesting adjustments in the price level back to its steady-state value, which determined by the loan-to-deposit ratio according to Eq. (10). More specifically, each month, around 8% of the log HICP deviation from the equilibrium is corrected in the long run.

The ECT coefficients at the loan-to-deposit equation (14) are statistically significant in each vector ( $\eta^3 = -0.30748$ ,  $\mu^3 = -0.11187$ ). More specifically, due to  $v_1$ , the departure of the ratio from its steady state is corrected by around 31%, and, concerning  $v_2$ , by about 11%. Regarding the real interest rate, however, the coefficients are non-significant in any ECT. Accordingly, the two other variables, mainly and very interestingly the loan-to-deposit ratio, react the most to the system disequilibrium and are therefore responsible for the long-run return to the steady state.

Summing up, we conclude that in the event of a deviation from the steady-state, significant adjustments toward the long-run equilibrium within the previously outlined monetary model, transmission mechanisms, and debt–deflation theory took place in the Eurozone during the crisis interval. Two essential conclusions arise from this VEC analysis of the long run, both coincident with the salient features found by previous empirical studies. First, these long-run adjustments, guided by the response of the Eurozone economy to the ECB monetary policy, are essential determinants of the observed evolution of the variables. Second, the leverage decisions of the financial sector constitute a crucial element in explaining the Eurozone monetary transmission.

**Short-run dynamics.** As explained above, the steady relationships identified by the cointegration equations constitute a key determinant in the long-run dynamics. In addition and as is well known (see, for instance, Fernández-Villaverde et al., 2016), the short-run dynamics, although convergent to the one dictated by the steady state, respond to additional specific factors and have a more complex nature. As usual in this class of general equilibrium models, our model does not have an algebraic solution, only a numerical one. Consequently, studying the short-run dynamic relationships between variables in our model is only possible after calibrating and simulating the economy and once a numerical method has been previously applied. In our model, which introduces a new concept of equilibrium, this would imply the need for considerable additional research, both theoretical and practical. This is so because our monetary general equilibrium model includes the financial leverage  $\gamma$  as an endogenous variable implicitly determined, and, to our knowledge, there is no numerical solution method properly addressing this situation: the Euler equations derived from the equivalent social planner's problem must be solved for each value of  $\gamma$ , which, in turn,



**Fig. 4 Impulse-response functions.** The shaded area around each solid line represents the 95% confidence interval for the estimates. The x-axis measures months after impact; the y-axis corresponds to changes in percentage (real interest rate), logarithm (core HICP), and value (leverage ratio).

depends on the solution for this system. In this respect, our VEC analysis helps to disentangle the specific variables and channels working in the short run by identifying and quantifying them. Moreover, it also allows for a theoretical interpretation of the channels and relationships working in the short-run.

The short-term analysis relies prominently on the VEC model's impulse response functions (IRFs) specified with levels and Cholesky identification. As shown in Toda and Yamamoto (1995), Dolado and Lutkepohl (1996), and Kilian and Lutkepohl (2017), VAR models in levels are robust to alternative cointegration ranks and vector specifications. In addition, as concluded by Elliott and Stock (1994), Cavanagh et al. (1995), and Canova (2007), these models solve the controversial issue of which cointegration restrictions to impose as well as potential unit root problems.

Before estimating the IRFs, we introduced the Cholesky decomposition of the variance-covariance matrix by assuming the following recursiveness in the model. First, following the tradition of Cholesky ordering originating from Sims (1980), we expect no simultaneous impact of the real interest rate innovation on the price level. Furthermore, the real interest rate and prices respond to the leverage shock only by a month's delay. Lastly, assuming that the reaction of prices to shocks in the other variables is not simultaneous but delayed, the price index is ordered first in the zero restrictions, which lets all variables freely move contemporaneously on its impact.

Figure 4 depicts the IRFs' output generated for a 24-month horizon. The shaded area around each solid line represents the 95% confidence interval on the estimates. Considering both

medium- and long-run responses for each theoretical link, the IRFs conform to our theoretical finding of a monetary transmission mechanism incorporating debt-deflation channels. First, a real interest rate shock induces a persistent decline in the leverage ratio, which becomes significant after three months lasting for over a year and a half. The price index response is positive following an innovation in the leverage ratio, being significant for about half a year from the fifth month. Interestingly, a shift in the leverage ratio has a self-reinforcing effect, a feature coherent with the deleveraging and debt-deflationary circular process as well as with the great relevance found for the loan-to-deposit ratio coefficients in the long-run cointegration equations. This result conforms to the occurrence of a private sector's *en masse* deleveraging process, leading to a subsequent reduction of loans by the whole financial sector. Most notably, the latter is consistent with the implementation in the Eurozone of tightening macroprudential policies that affect the banking sector as a whole and cause descents in the volume of loans, a question to which we return later. As for inflation, shocks have a persistent and significant positive effect on itself and a significant simultaneous positive effect on the leverage ratio, potentially enhancing a feedback debt-deflation mechanism. To conclude the IRF medium/long-run responses, the results are aligned with the theoretical findings and the VECM analyses. In particular, they confirm the existence of long-run relationships determined by the ECB monetary policy, which guides the dynamics through monetary transmission mechanisms that imply debt-deflation links strongly dependent on the financial leverage decisions.

Concerning the short-run dynamics, it is useful to start with some considerations about its interpretation. Like any statistical simulation, VEC modeling performs IRFs based on the considered data. In this regard, the IRFs must be placed within the financial crisis scenario, a period in which the economic policies adopted in the Eurozone were very diverse and primarily non-standard. In the case of fiscal and monetary policies, they presented a clear expansionary character, as described among others by Coenen et al. (2012), González-Páramo (2009), Attinasi et al. (2019), Ross et al. (2019) or Fiedler and Gern (2019). Furthermore, to ensure financial stability, several macroprudential tightening policies were also implemented, resulting in the co-existence of several factors affecting short-term shocks (see Aiyar et al., 2014; Benchimol et al., 2022; Cerutti et al., 2017; IMF International Monetary Fund, 2013).

Consequently, a proper interpretation of the IRFs' analysis through the lens of the theoretical results requires considering the economic conditions from which the data originated. More specifically, in the face of an expansionary fiscal policy during economic stagnation, the presence of an immediate crowding-out rising effect on the interest rate linked to public debt increase is highly likely. Thus, the shocks in interest rates modeled by the impulse response analysis in Fig. 4 would probably correspond, in a substantial part, to these effects of the expansionary monetary policies. This would explain the subsequent increase in inflation during the periods immediately after the increase in the interest rate, both associated with the short-term effects of the expansionary fiscal policy. As time passes, and according to the theoretical results of the proposed GE model, also identified by the implemented VEC model, the long-term adjustments dictated by the monetary policy occur. These adjustments, caused by the presence of debt–deflation elements, imply a negative relationship between interest rates and inflation, as appears in Fig. 4 from the eighth period for the price level and after the ninth month for the interest rates.

Regarding inflation shocks, the real interest rate response in the first eight months is positive but insignificant, possibly due to the ambiguous short-term relationship between the two variables and their timing. The stagnant environment of the financial crisis makes it unlikely that price increases would be a short-run consequence of the implemented expansionary fiscal policies. However, the functioning of the monetary policy can provide a satisfactory explanation. More specifically, while a deflationary shock generally induces expansionary monetary policy, driving the nominal and then the real interest rate downward, the same shift in the price level increases the real interest rate through the Fisher equation and the adjustment in the expected inflation. Thus, the final effect depends on the relative capability of the monetary policy and the expected path of the inflation rate. On this point and as the related IRF suggests, the former was larger than the latter in the post-crisis era, likely due to the precedence of the liquidity effect to the Fisher effect (see for instance Monnet and Weber, 2001). The observed increases in inflation therefore have consequences for the interest rate through their involvement in monetary transmission mechanisms, with a greater long-term character and according to the presence of debt–deflation elements implying decreases in the interest rate. The IRF of the real interest rate on the impact of the leverage shock suggests a similar constraint. In this regard, although the real interest rate responds positively, reflecting an adequate policy intervention, it remains insignificant in the whole horizon.

As happened in the long run, the short-run dynamics of the leverage ratio are, in part, determined by implementing a wide variety of tightening macroprudential tools. The effects of macroprudential policies, however, are unclear due to their diversity and high dependence on the specific situation of the

considered economy, especially on the degree of economic openness and the level of financial interdependence (see Ampudia et al., 2021; Benchimol et al., 2022; Boar et al., 2017; Bussière et al., 2021). Nevertheless, regarding the tightening macroprudential policies applied in the Eurozone during the GFC period (see EUC European Union Commission, 2014), there exists clear theoretical and empirical evidence for two effects. In the very long-run, these policies ensure a higher total volume of bank loans as they foster financial sector robustness and bank mergers; however, in the short-run and especially when they are applied in a stagnation scenario, they produce a contraction in the aggregate volume of bank loans (see Cerutti et al., 2017; Drehman and Gambacorta, 2012; IMF International Monetary Fund, 2013; Jiménez et al., 2017). This short-run decline in bank credits constitutes a plausible explanation for the pronounced response of the leverage ratio after each innovation. The crisis period was characterized by frequent and intense drops in stock market prices, leading to increases in interest rates, and accompanied by descents in real activity, bank collapses, and higher risks for the financial system. To respond to this turmoil and ensure resilience and a more robust financial sector, the Eurozone applied a battery of tightening macroprudential tools. Therefore, these events are partly responsible for the model variable innovations. The strong and immediate positive response of the leverage ratio to its own shock during the first six months is consistent with the *en masse* contractive effects on bank loans caused by tightening macroprudential policies. This also applies to the progressive descent in leverage after a real interest rate innovation, since stock market turmoil, asset price descents, and increases in interest rates are signals preceding the implementation of macroprudential tools. Finally, the positive and much weaker leverage response after a price level shock is consistent with the evidence of the insignificant effects of tightening macroprudential policies on inflation (Cerutti et al., 2017).

To conclude, the empirical analysis carried out with the structural VECM confirms the findings and conclusions of our theoretical model. On the one hand, data suggest the existence of the two long-run steady-state relationships between price level, real interest rates, and the leverage ratio predicted by the stylized model, thus explaining the transmission mechanism and the model's long-run dynamics. In line with the theoretical sign of those relationships, the VECM shows the existence of a debt–deflation propagating mechanism that constitutes a vicious circle. In particular, we have found that increases in real bank lending rates driven by falling prices reduce lending activity and initiate a deleveraging process. This process leads to a deflationary environment that again reduces lending activity through the rise in the real debt burden. The IRF analysis suggests that essential short-run effects are associated with implementing expansionary fiscal policies and tightening macroprudential measures. Expansionary fiscal policies and their association with the evolution of public sector indebtedness, in the short-run, affect the economy by raising interest rates and then prices. Increases in prices, on the other hand, have consequences on the interest rate through their involvement in the monetary transmission mechanisms, with a more significant long-term character and according to the presence of debt–deflation elements. Finally, macroprudential tightening policies are a plausible candidate for partially explaining the leverage ratio's short-run responses on impacts.

**Interval extension.** An effective way to assess the generality of our theoretical prediction and the robustness of the empirical analysis is to run the VECM on an extended time series, including the pre-crisis period. More specifically, the new interval covers

**Table 4 Johansen cointegration test—extended interval.**

Hypothesized no. of CE(s)	$r = 0$	$r \leq 1$	$r \leq 2$
Trace	52.20692***	22.34862	8.29289
Eigenvalue	29.85831**	14.05573	8.29289

Trace represents the trace test statistics and eigenvalue is the maximal eigenvalue test statistics. \*\*\*, \*\* denote rejection of the null hypothesis at the 1% and 5% significance levels.

**Table 5 ECTs coefficients—extended interval.**

ECTs	$\Delta r^P$	$\Delta \gamma$	$\Delta \pi$
$\eta_{v1}$	-6.24503* (3.53898)	-0.00606 (0.04486)	-0.03549*** (0.01069)
$\mu_{v2}$	-0.09399*** (0.02941)	0.00027 (0.00037)	-0.00014 (8.9E-05)

Numbers in parentheses are *t*-statistics. \*, \*\*\*, denote  $p < 0.10$  and  $p < 0.01$ , respectively.

the period from January 1999, the introduction of the euro, until December 2020, the period preceding the Covid-19 pandemic.

After ensuring that each variable follows an I(1) process, we perform the Johansen test. Notably, the test results in Table 4 indicate one cointegration vector instead of two within the standard significance level, which suggests that one of the relationships defined by the theoretical prediction became weaker. For a more informed assessment of the rejection of the two cointegration equations, we explicitly report the related *p*-values for the trace and eigenvalue statistics, which are 0.1291 and 0.2505, respectively. Moreover, to be consistent with the theoretical model, we impose an equal number of cointegration relationships (see Canova, 2007). Taking these considerations into account, we include two cointegrating vectors in the extended model.

The coefficients in the cointegration equations (15, 16) reflect the same associations as expected by the stylized model. However, when studying the ECT coefficients in Table 5, it becomes evident that the adjustments in the variables follow a different pattern compared to the GFC interval. In particular, the adjustment of the loan-to-deposit ratio to the steady state becomes insignificant. Instead, the real interest rate and the price level convergences dominate in achieving the long-run equilibrium ( $\eta^2 = 0.03549$ ,  $\mu^1 = 0.09399$ ).

$$\pi_t = 4.33029 + 0.00102t + 0.18004\gamma_t \tag{15}$$

$$\gamma_t = -2.66626 + 0.01938t - 0.75793r_t^P \tag{16}$$

When studying the IRFs in Fig. 5, it is apparent that the short-term dynamics evolve somewhat differently compared to the crisis period. Most prominently, leverage shocks induce a stronger positive response in the real interest rate, indicating a higher effectiveness of monetary policy when the extended period is considered. This is consistent with the absence during the pre-crisis period of expansionary fiscal policies and crowding-out shocks in the interest rates and with the subsequent relative higher response of the interest rates to purely monetary and financial measures.

In addition, in the extended interval, a positive shock in real interest rates does not reduce the leverage ratio, and the leverage response on the impact of a price shock differs from the one during the GFC, displaying an exclusively positive response. The altered dynamics between the leverage ratio and the other variables are all potentially associated with the occurrence of sharp economic changes before, during and after the financial crisis. The overheated economic environment experienced in the pre-crisis period, and especially the housing boom, explains the co-movements of interest rates and leverage. The relatively large, persistent, and positive response of the leverage ratio on its own impact, the positive and progressive increase in this variable after innovations in prices and interest rates, and the higher interest rates after a leverage shock are very likely related to the substantial feedback increases in loan activity in the pre-crisis period, with a clear speculative component consequence of the

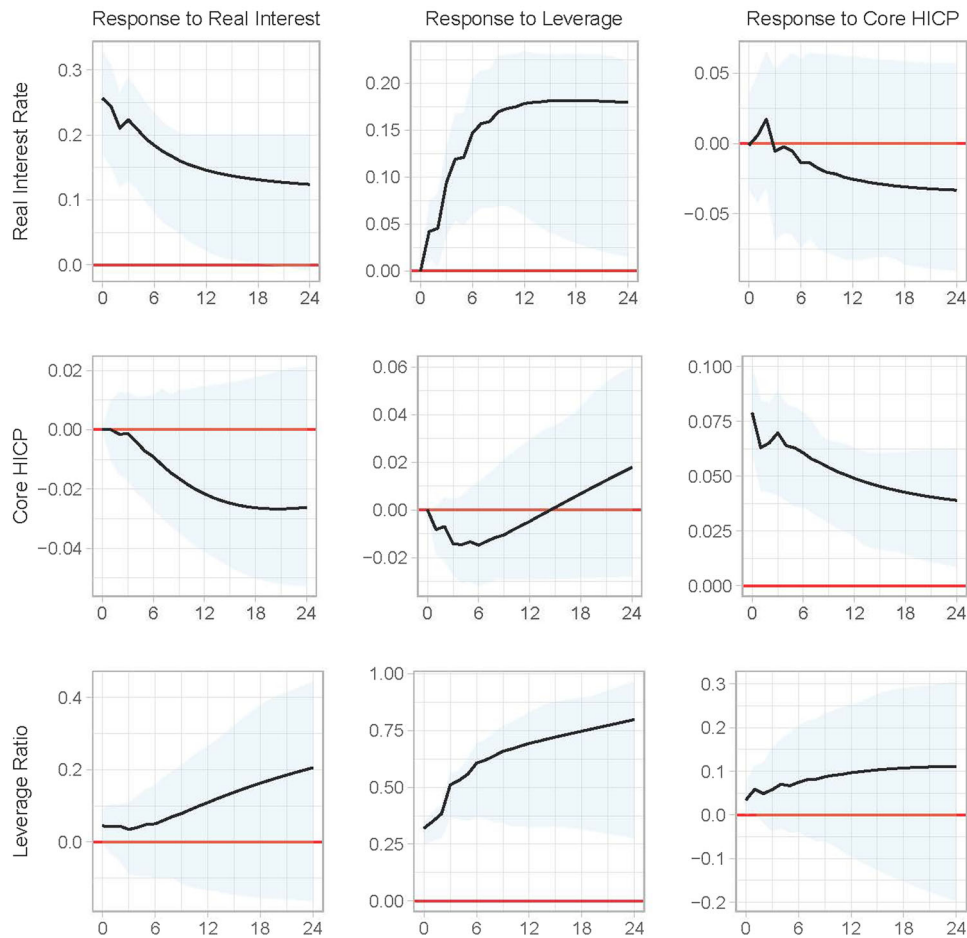
housing boom. On this point, it is worth noting that the previously reported long-run leverage ratio adjustment, although non-significant, is consistent with the above considerations. Finally, the response of the core price index to the leverage ratio innovation is negative, although insignificant, for about a year. The rest of the IRFs are comparable to those discussed in the crisis short-term analysis.

To conclude, the extended analyses deliver comparable results in the long-term dynamics. They reveal, however, structural differences primarily due to the nature of the post and pre-crisis regimes. While the real estate bubble and the overheated economy characterized the pre-crisis period, the bursting of the bubble, the emergence of bankruptcies, the subsequent macroprudential tightening tools, and the implementation of expansionary fiscal policies, were some of the salient features of the GFC economy. The distinct IRFs obtained in the two considered periods evidence this structural change, very likely also related to the changes during the crisis in the degree of interdependence of the Eurozone and US financial systems. This issue, analyzed by Belke and Cui (2010) and Benchimol and Ivashchenko (2021), has relevant implications for the monetary transmission mechanism that will be commented on in the Conclusions section. In this respect, the altered short-term dynamics of our IRF analysis reflect the potential non-linearities in the monetary transmission mechanisms identified by Benchimol and Ivashchenko (2021) with a two-country general equilibrium model and motivate further research on this subject.

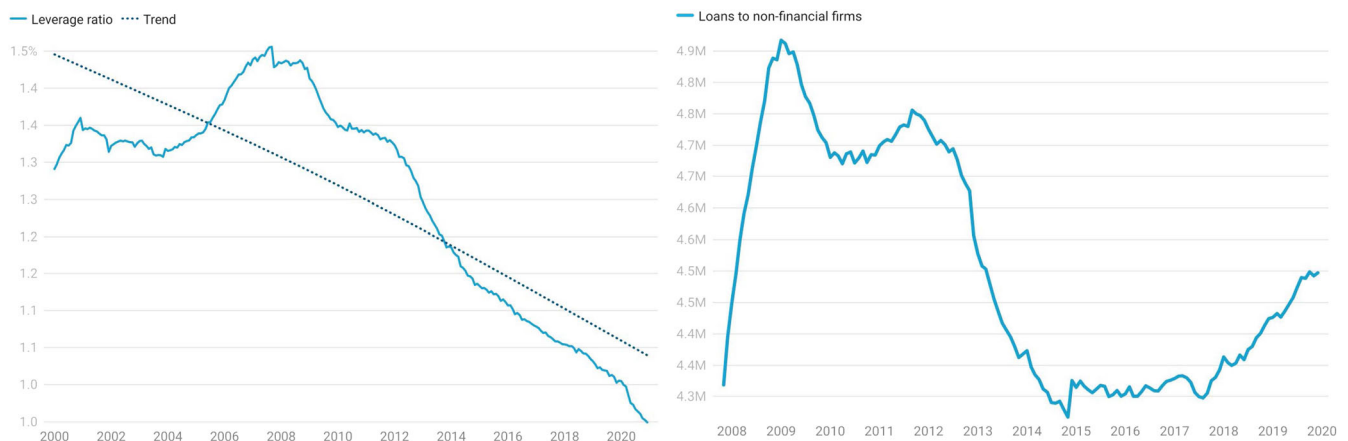
**Returning to the loan-to-deposit ratio.** As discussed in the theoretical section and as the steady-state Eqs. (8) and (9) state, that the loan-to-deposit ratio  $\gamma$  plays a crucial role in clarifying how monetary policy affects the economy. Indeed, this ratio appears as the key variable in the monetary transmission mechanism, linking the reserves coefficient  $s_t$  and the money supply changes  $g_b$ , determined by the ECB, with all the real and nominal variables of the economy. An analysis of this variable from the empirical perspective sheds additional light on its paramount relevance in explaining the recent crisis.

As Fig. 6 depicts, during the 2008-2018 period, the loan-to-deposit ratio suffered a significant contraction, mainly due to the large fall in the aggregate loans provided to the production sector. Given its definition  $\gamma_t = (1 - s_t + \rho_b g_t)$  and the monetary policy implemented by the ECB, characterized by a constant reserve coefficient and increases in the money supply, this decrease must necessarily obey a fall in  $\rho_b$ , the parameter measuring the percentage of money supply changes lent to the non-financial firms. Therefore, it is of paramount importance to reveal what contributed to this decrease in  $\rho_t$  and why the financial firms opted to diminish the percentage of deposits intended for loans to the production sector.

One of the reasons explaining this descent in  $\rho$  is the previously commented short-run contractionary effect on the volume of bank loans caused by the tightening macroprudential policies



**Fig. 5 Impulse-response functions—extended interval.** The shaded area around each solid line represents the 95% confidence interval for the estimates. The x-axis measures months after impact; the y-axis corresponds to changes in percentage (real interest rate), logarithm (core HICP), and value (leverage ratio).



**Fig. 6 Evolution of leverage and loans for the Eurozone.** Loan-to-deposit ratio (left) and loans to non-financial firms (right), Eurozone.

applied in the Eurozone. As Drehman and Gambacorta (2012) and Jiménez et al. (2017) report, in turmoil episodes, the difficulties of the market to freely and efficiently allocate financial resources following these policies result in a reduction of loans. Undoubtedly this happened in the Eurozone, but it is not the only factor, or, at least, the unique dimension to be taken into account. Given the structural nature of this parameter and assuming a competitive financial market for the Eurozone, the answer is also potentially related to the heightened concern of banks for

liquidity during this financial crisis, and with their aim of minimizing the probability of default in a competitive environment. This issue, present in the economic debate from studies by Diamond and Dybvig (1983), is fundamental in our context since it is related to the optimal level of bank capital requirements, how this capital requirement affects the provision of credit and thus the volume of loans to the economy, and how the default risks of financial and non-financial firms are related. The explanation of these issues remains open, and is the subject of a large body of

literature (see, for instance, Mendicino et al., 2021; Nagel Purnanandam, 2020, and the references therein).

While our model does not specifically analyze these particular topics, it does solve relevant connected aspects. First, in light of the data, the increase in bank capital requirements in the Eurozone throughout the GFC has not avoided descents in  $\rho_t$ , nor in  $\gamma$  or the variables positively related to it, for example, output, consumption, and investment. It suggests that the level of bank capital requirements is far from its optimum or that, although it reduces the probability of default, this measure is not effective enough in attaining higher investment and output due to the response of the banks. As Mendicino et al. (2021) pointed out, these situations are theoretically possible and could apply to the Eurozone. Then, how can the decrease in  $\gamma_t$  be reversed? Our model provides an answer since, according to the steady-state equations, this loan-to-deposit ratio negatively depends on the margin  $m_t$ . Since

$$\gamma = 1 - \frac{m}{\alpha(\gamma d)^{\alpha-1}}, \quad d = \left[ \frac{\alpha\beta\gamma^\alpha}{\delta\beta + 1 - \beta} \right]^{\frac{1}{1-\alpha}},$$

substituting  $d$  into the first equation, we obtain

$$\gamma = \frac{1}{1 + Am},$$

where  $A$  is a positive constant.

The ECB did not explore this option completely along the GFC. In 2008, the corridor was at 1 pp, and from 2008 to 2013, this margin continuously remained above this value: 2 pp until 2009 and 1.5 pp from 2009 to 2013. Only from November 2013 was this margin below its value in 2008, being 0.75 pp in 2018. Simultaneously, the ECB imposed negative rates for the deposit facility from June 2014, a clear measure pursuing an increase in  $\rho$  and thus in the leverage ratio, with the ultimate goal of breaking the vicious circle implicit in the identified debt–deflation mechanisms. As our model predicts, 2014–2018 coincides with significant and continuous increases in the GDP growth rate and the recovery in loans to productive firms (Fig. 6). It is an additional sign of the theoretical consistency of our introduction of the different monetary policy instruments into the model, which allows their specific role in the monetary transmission mechanism to be disentangled.

Returning to the literature on bank default, it is worth noting that the decrease in  $m_t$  is consistent with increases in  $\rho_t$ , at least through two channels. First, given the interactions between the defaults of financial and non-financial firms (see Mendicino et al., 2021), this decrease in the corridor  $m_t$  and the subsequent increase in  $\gamma_t$  leads to an economic recovery that can explain descents in the probability of default of the financial intermediaries, and then to an increase in  $\rho_t$ . Second, since reducing the width of the corridor causes lower volatility for interest rates, the decrease in  $m_t$  could be associated with a fall in the uncertainty faced by financial intermediaries and in their probability of default, and therefore to an increase in  $\rho_t$ . Recent studies on the optimal width of the standing facilities corridor focus on this and other related questions (see Bindseil, 2014 and the references therein.)

## Conclusions

Due to the particular features of the worldwide crisis that began in 2008, Economic Theory has renewed its concern about the objectives and instruments of monetary policy and the channels through which this policy operates, the so-called monetary transmission mechanism. It is particularly true for the Eurozone, where the economic crisis has been characterized by an astonishing mix of expansionary monetary policies, declines in the

price level, a descent of credit flows and, thus, of the productive sector debt, and pronounced decreases in real activity. By employing mainly structural macroeconomic and VAR models, the empirical literature analyzing these issues for the Eurozone has concluded the adoption by the ECB of a long-run inflation objective for the monetary policy, the existence of a transmission mechanism implying debt–deflation processes, and the essential role played by the bank lending channel in this mechanism. This paper is the natural continuance of this line of research, proposing a monetary general equilibrium model that consistently explains these questions.

More specifically, we formulate an extended version of the limited participation models proposed by Fuerst (1992) and Christiano and Eichenbaum (1992) and developed by Gutiérrez (2006) and Gutiérrez and Palmero (2013). The key variable is the loan-to-deposit ratio of the financial sector. Through this variable, the model can explain the existence of long-run relationships driving the monetary policy of the ECB and linking inflation, interest rates, bank loan volumes, the functioning of the monetary transmission mechanism, and the presence of debt–deflation channels. This stylized monetary general equilibrium model is used to justify an empirical analysis developed by applying a VECM, which confirms and quantifies the role of the obtained long-run relationships in the dynamics of the monetary transmission in the Euro economy and the existence of debt–deflation processes. Furthermore, through the analysis of the VEC model's IRFs and keeping in mind the peculiarities of the considered period, our double theoretical-empirical approach allows for a theoretical interpretation of the channels and relationships working in the short-run.

The findings of our research provide valuable insights, for both policy makers and theoretical researchers. Regarding the former aspect, we can interpret recent monetary policy measures and extract some policy recommendations for the immediate future from our results. As a fact, some of them have already been applied to mitigate the COVID-19 pandemic. Given the existence of debt–deflation mechanisms in the Eurozone economy pivoting on the evolution of the loan-to-deposit ratio, some monetary policy measures have been or could be, implemented directly through this ratio. As we have explained, one particularly interesting variable susceptible to modification by the ECB and affecting financial leverage is  $\rho$ , the percentage of money increases reaching productive firms. In this respect, the negative rate imposed by the ECB for the deposit facility from June 2014 is a clear measure pursuing an increase in  $\rho$  and thus in the leverage ratio, with the ultimate goal of breaking the vicious circle implicit in the identified debt–deflation mechanisms. The narrowed standing facilities corridor could also imply increases in  $\rho$  through decreases in the probability of the default of financial firms, a relevant question in the current research agenda that our model can clarify. Given the close relationship between  $\rho$  and the financial market structure and competitiveness, macroprudential policies aiming to restructure the European banking sector to improve financial stability and to complete the EU single market (see the *Financial Integration and Structure* ECB publications) must also be understood as measures pursuing an increase in the financial leverage  $\gamma$  in the long-run.

Another possibility is to decrease the legal reserves coefficient since this would imply higher leverage, i.e., higher relative loans. This coefficient was 1% from 18 January 2012, so the ECB has some room for this decrease. In addition, the ECB can also augment the loan-to-deposit ratio by fixing higher money supply increases  $g$ . Specifically, relying on the output of our structural factor analysis, quantitative easing also influences the real interest rate and the price level, thus validating the ECB's extended Asset Purchase Program implemented to fight the Covid-19



pandemic<sup>10</sup>. Yet, considering the retained downward pattern in the leverage ratio during the previous expansive monetary policy periods, its exclusive capability to halt the deleveraging process remains ambiguous, justifying the co-existence during the Pandemic Emergency Program of a broad range of measures such as those noted here. As Grandi (2019) pointed out, the above-suggested structural financial policies aiming to complete the banking union would improve the homogeneity and effectiveness of the bank lending transmission channel and the efficiency of the monetary easing measures. In addition, the upward revision of the inflation objective agrees with all our theoretical and empirical findings, even expanding government purchases as a complementary remedy for economies subject to debt–deflation mechanisms (see, for instance, Ball, 2014; Blanchard et al., 2010; Murota and Ono, 2015). Indeed, as suggested by our analyses, both measures have lately been adopted by the Eurozone.

From the theoretical perspective, our analyses open several interesting research avenues. First, our paper contributes to advances in macroeconomic research focusing on the role of the financial sector in the generation and propagation of real fluctuations, at the heart of the current agenda since the GFC. In particular, through the identified debt–deflation channels, our monetary GEM highlights how the financial and real variables are interrelated and constitute a viable alternative to explain the close co-movements between these two cycles. In the same way, deflation and descents in the volume of credit and aggregate demand are related, so are inflation and increases in bank loans and aggregate demand, and thus our model provides a unified framework to explicate real and financial cycles and their time relationships. Indeed, according to our theoretical model, financial and real cycles are strictly speaking the two sides of a unique phenomenon, a conclusion also reached from recent empirical studies on this issue (see Rünstler et al., 2018 and the numerous references therein). Given that in our model this link between financial and real cycles rests on the loan-to-deposit ratio of the financial sector  $\gamma$ , the study of formulations of  $\gamma$  specifying its dependence on household and bank leverage ratios opens up an interesting path for the analysis of the role played by housing and collaterals. As Gerali et al. (2010) and Falagiarda and Saia (2017) conclude, the dynamics for the Eurozone of the total volume of loans, and therefore the interactions between the real and financial cycles, significantly depend on the leverage ratios of households and banks, mainly due to its endogenous nature with respect to the existing risk in the economy, collected by these leverage ratios. The possibility of formulating our loan-to-deposit ratio as a function of the capital adequacy ratio established for the financial sector and of the loan-to-value (LTV) ratio used by banks to estimate mortgage risk, as well as the endogenous nature of  $\gamma$  in our model, establishes a complementary and coherent link with this literature.

Our paper can also originate new theoretical approaches to study the implications for monetary policy of the structural economic changes inherent to crisis periods, another important strand of the current research in monetary economics. The nature of these structural changes is somewhat complex. Some are exogenously driven, as happens with macroprudential policies, but there exist others that seem to be intrinsic to each crisis period (see Benchimol and Fourçans, 2017; Hurtado, 2014 for the Eurozone). As the previously quoted work by Belke and Cui (2010), Bussière et al. (2021), and Benchimol and Ivashchenko (2021) show, the determination of their causes, relationships and consequences is also complicated, but, in any case, it is clear that these structural changes substantially affect the effectiveness of the monetary policy and need to be carefully modeled. Our study coincides with the findings of the cited authors, identifying changes in the monetary transmission mechanism and in the

effects of monetary policy specific to the GFC. In this regard, our VEC and IRF comparative analyses show that the GFC-specific monetary transmission mechanisms arise fundamentally from a different behavior and setting of the financial leverage variable, both in the long and short-run. This finding suggests that this financial variable is key to synthesizing and channeling the different structural changes contained in the GFC, therefore providing interesting avenues of analysis on the evidenced relevance of financial variables in the transmission mechanism.

### Data availability

Datasets and computer procedures used during the current study are publicly available at GitHub ([https://github.com/BeforePublication/Repository\\_definitive](https://github.com/BeforePublication/Repository_definitive)).

Received: 7 February 2022; Accepted: 14 August 2023;

Published online: 03 October 2023

### Notes

- 1 See, for instance, Fontana (2003), Palley (2002, 2013) or Benigno (2015).
- 2 See Champ and Freeman (2001, chs. 9 and 10) for a simple description. Deeper studies on their theoretical nature include Cavalcanti and Wallace (1999), Kiyotaki and Moore (2018), and the references therein.
- 3 See Freeman and Huffman (1991), Hartley and Walsh (1991), Chari et al. (1995), or Champ and Freeman (2001).
- 4 See Bernanke and Gertler (1995), Kuttner and Mosser (2002), von Peter (2005), Dedola and Lippi (2005), den Haan et al. (2007), Golinelli and Rovelli (2005), Adrian and Shin (2008, 2009) or Creel and Hubert (2015).
- 5  $D_t$ ,  $K_t^P$  and  $K_t^F$  are decided at period  $t-1$ , where the price is  $p_{t-1}$ . For a detailed explanation of this question, see Gutiérrez (2006).
- 6 It is straightforward to show that  $\delta = \frac{\delta^P K_t^P + \delta^F K_t^F}{K_t^P + K_t^F}$ , where  $\delta^P$  and  $\delta^F$  are, respectively, the depreciation rate of productive and financial capital.
- 7 See for instance Blenck et al. (2001).
- 8 These SPF averages or SPF sample averages that we use ignore behavioral biases that arise from the unique educational background, past economic experiences, and work experience of each forecaster (see Benchimol et al., 2022).
- 9 According to Ivanov and Kilian (2012), AIC performs best for monthly data VAR.
- 10 The Pandemic Emergency Purchase Program (PEPP) had an overall envelope of 750 billion euros. Purchases were conducted until the end of 2020 and included all the asset categories eligible under the previous asset purchase program.

### References

- Adrian T, Shin HS (2008) Liquidity, monetary policy, and financial cycles. *Curr Issues Econ Finance* 14:1–7
- Adrian T, Shin HS (2009) Prices and quantities in the monetary policy transmission mechanism. *Int J Central Bank* 5:131–142
- Ahking FW (2002) Model mis-specification and Johansen's co-integration analysis: an application to the US money demand. *J Macroecon* 24:51–66
- Aiyar S, Calomiris CW, Wieladek T (2014) How does credit supply respond to monetary policy and bank minimum capital requirements? Bank of England, Working Paper 508
- Allen F, Gale D (2004) Competition and financial stability. *J Money Credit Bank* 36:453–80
- Amputia M, Lo Duca M, Farkas M, Perez-Quiros G, Rünstler G, Tereanu E (2021) On the effectiveness of macroprudential policy. ECB Working Paper 2021/2559
- Angeloni I, Kashyap AK, Mojon B, Terlizzese D (2002) Monetary transmission in the Euro area: where do we stand? ECB Working Paper 114
- Attinasi MG, Palazzo AA, Pierluigi B (2019) Fiscal activism in the euro area and in other advanced economies: new evidence. European Central Bank Working Paper Series 2344
- Baimbridge M, Whyman PB (2015) Crisis in the Eurozone. Causes, dilemmas and solutions. The Palgrave Mcmillan, New York, USA
- Ball L (2014) The case for a long-run inflation target of four percent. IMF Working Paper 14/92
- Belke A, Cui Y (2010) US-Euro area monetary policy interdependence: new evidence from Taylor rule-based VECMs. *World Econ* 33:778–797
- Benchimol J, Bozou C (2022) Desirable banking competition and stability. Bank of Israel Working Papers 2022.18

- Benchimol J, El-Shagi M, Saadon Y (2022) Do expert experience and characteristics affect inflation forecasts? *J Econ Behav Organ* 201:205–226
- Benchimol J, Fourçans A (2017) Money and monetary policy in the Eurozone: an empirical analysis during crises. *Macroecon Dyn* 21:677–707
- Benchimol J (2022) The interaction between domestic monetary policy and macroprudential policy in Israel. *Econ Model* 112:105872
- Benchimol J, Ivashchenko S (2021) Switching volatility in a nonlinear open economy. *J Int Money Finance* 110:102287
- Benigno P (2015) New-Keynesian economics: an AS-AD view. *Res Econ* 69:503–524
- Bernanke B (1983) Nonmonetary effects of the financial crisis in propagation of the great depression. *Am Econ Rev* 73:257–76
- Bernanke BS, Gertler M (1995) Inside the black box: the credit channel of monetary policy transmission. *J Econ Perspect* 9:27–48
- Bindseil U (ed) (2014) Standing facilities and the Interest Rate Corridor. In: *Monetary policy operations and the financial system*. Oxford University Press, pp. 70–83
- Blanchard O, Dell’Ariccia G, Mauro P (2010) Rethinking macroeconomic policy. *J Money Credit Bank* 42:199–215
- Blenck D, Hasko H, Hilton S, Masaki K (2001) The main features of the monetary policy frameworks of the Bank of Japan, the Federal Reserve and the Eurosystem. *BIS Papers* 9
- Boar C, Gambacorta L, Lombardo G, Pereira da Silva L (2017) What are the effects of macroprudential policies on macroeconomic performance? *BIS Q Rev* September:71–88
- Bonci R, Columba F (2008) Monetary policy effects: new evidence from the Italian flow-of-funds. *Appl Econ* 40:2803–2818
- Brealey RA, Myers SC, Franklin A (2014) *Principles of corporate finance*. Series in finance, insurance, and real estate. MacGraw-Hill
- Bussière M (2021) The interaction between macroprudential policy and monetary policy: overview. *Rev Int Econ* 29:1–19
- Bussière M, Sahuc J-G, Pfister C (2020) The link between money and inflation since 2008. *Bulletin de la Banque de France* 232
- Canova F (2007) *Methods for applied macroeconomic research*. Princeton University Press
- Căpraru B, Ihnatov I, Pintilie N-L (2020) Competition and diversification in the European Banking Sector. *Res Int Bus Finance* 51:100963
- Caporale GM, Kontonikas A (2009) The Euro and inflation uncertainty in the European Monetary Union. *J Int Money Finance* 28:954–971
- Cardinale I, Coffman D’M, Scazzieri R (eds) (2017) *The political economy of the Eurozone*. Cambridge University Press
- Cavalcanti R, Wallace N (1999) Inside and outside money as alternative media of exchange. *J Money Credit Bank* 31:443–457
- Cavanagh CL, Elliott G, Stock J (1995) Inference in models with nearly integrated regressors. *Econom Theory* 11:131–1147
- Cerutti E, Claessens S, Laeven L (2017) The use and effectiveness of macroprudential policies: new evidence. *J Financ Stab* 28:203–224
- Champ B, Freeman S (2001) *Modeling monetary economics*, 2nd edn. Cambridge University Press
- Chang M, Steinberg F, Torres F (eds) (2019) *The political economy of adjustment throughout and beyond the Eurozone crisis. What have we learned? UACES contemporary European studies*. Routledge
- Chari V, Christiano L, Eichenbaum M (1995) Inside money, outside money, and short-term interest rates. *J Money Credit Bank* 27:1354–1386
- Christiano LJ, Eichenbaum M (1992) Liquidity effects and the monetary transmission mechanisms. *Am Econ Rev* 82:346–353
- Claessens S, Kose MA, Terrones ME (2012) How do business and financial cycles interact? *J Int Econ* 87:178–190
- Clower RW (1967) A reconsideration of the microfoundations of monetary theory. *Western Econ J* 6:1–9
- Coenen G, Straub R, Trabandt M (2012) Fiscal policy and the great recession in the Euro area. *Am Econ Rev* 102:71–76
- Cooley TF, Prescott EC (1995) Economic growth and business cycles. In: Cooley and Prescott (eds) *Frontiers of business cycle research*. Princeton University Press, pp. 1–38
- Corsetti G, Kuester K, Meier A, Müller GJ (2013) Sovereign risk, fiscal policy, and macroeconomic stability. *Econ J* 123:F99–F132
- Creel J, Hubert P (2015) Has inflation targeting changed the conduct of monetary policy? *Macroecon Dyn* 19:1–21
- Cruz-García P, Fernández de Guevara J, Maudos J (2017) The evolution of market power in European banking. *Finance Res Lett* 23:257–262
- Dedola L, Lippi F (2005) The monetary transmission mechanism: evidence from the industries of five OECD countries. *Eur Econ Rev* 49:1543–1569
- Deleidi M (2018) Post Keynesian endogenous money theory: a theoretical and empirical investigation of the credit demand schedule. *J Post Keynes Econ* 41:185–209
- Diamond DG, Dybvig PH (1983) Bank runs, deposit insurance, and liquidity. *J Political Econ* 91:401–419
- Dolado JJ, Lutkepohl H (1996) Making Wald tests work for cointegrated VAR systems. *Econom Rev* 15:369–386
- Drakos AA, Kouretas GP (2015) The conduct of monetary policy in the Eurozone before and after the financial crisis. *Econ Model* 48:83–92
- Drehman M, Gambacorta L (2012) The effects of countercyclical capital buffers on bank lending. *Appl Econ Lett* 19:603–608
- ECB European Central Bank (2010) Monetary policy transmission in the euro area, a decade after the introduction of the Euro. *Mon Bull* May:85–98
- ECB European Central Bank (2012) Special features. *Financ Stab Rev* June:105–115
- Elliott G, Stock J (1994) Inference in time series regression when the order of integration of a regressor is unknown. *Econom Theory* 10:672–700
- EUC European Union Commission (2014) A comprehensive EU response to the financial crisis: Substantial progress towards a strong financial framework for Europe and a banking union for the Eurozone. *Memo/14/244*
- Falagiarda M, Saia A (2017) Credit, endogenous collateral and risky assets: a DSGE model. *Int Rev Econ Finance* 49:125–148
- Fernández-Villaverde J, Rubio-Ramírez JF, Schorfheide F (2016) Solution and estimation methods for DSGE models. In: Taylor JB, Uhlig H (eds) *Handbook of macroeconomics*, vol 2. Elsevier, pp. 527–724
- Fiedler S, Gern K-J (2019) Monetary policy in the Euro area after eight years of presidency of Mario Draghi: where do we stand? *Monetary dialogue*. Policy Department for Economic, Scientific and Quality of Life Policies, European Union
- Fisher I (1933) The debt–deflation theory of great depressions. *Econometrica* 1:337–357
- Fontana G (2003) Post Keynesian approaches to endogenous money: a time framework explanation. *Rev Political Econ* 15:291–314
- Freeman S, Huffman G (1991) Inside money, output, and causality. *Int Econ Rev* 32:646–667
- Fuerst TS (1992) Liquidity, loanable funds, and real activity. *J Monetary Econ* 29:3–24
- Gambetti L, Musso A (2017) Loan supply shocks and the business cycle. *J Appl Econ* 32:764–782
- Gerali A, Neri S, Sessa L, Signoretti FM (2010) Credit and banking in a DSGE model of the Euro area. *J Money Credit Bank* 42:107–141
- Giannone D, Lenza M, Reichlin L (2019) Money, credit, monetary policy, and the business cycle in the Euro area: what has changed since the crisis? *Int J Cent Bank* 15:137–173
- Golinelli R, Rovelli R (2005) Monetary policy transmission, interest rate rules and inflation targeting in three transition countries. *J Bank Finance* 29:183–201
- González-Páramo JM (2009) The response of the Eurosystem to the financial crisis. *BIS Central Bankers’ speeches* (13 Nov)
- Grandi P (2019) Sovereign stress and heterogeneous monetary transmission to bank lending in the euro area. *Eur Econ Rev* 119:251–273
- Gutiérrez PJ (2004) Money, prices and interest rates in a non-aggregate stochastic general equilibrium model. *Appl Math Finance* 11:283–316
- Gutiérrez PJ (2006) Short-run and long-run effects of monetary policy in a general equilibrium model with bank reserves. *Econ Model* 23:597–621
- Gutiérrez PJ, Palmero CR (2013) A note on the real effects of monetary shocks. *Macroecon Dyn* 17:936–946
- den Haan WJ, Sumner SW, Yamashiro GM (2007) Bank loan portfolios and the monetary transmission mechanism. *J Monet Econ* 54:904–924
- Hartley PR, Walsh CE (1991) Inside money and monetary neutrality. *J Macroecon* 13:395–416
- Heer B, Maussner A (eds) (2005) *Dynamic general equilibrium modelling*. In: *Computational methods and applications*. Springer, pp. 57–59
- Hodrick RJ, Kocherlakota N, Lucas D (1991) The variability of velocity in cash-in-advance models. *J Political Econ* 99:358–384
- Holtemöller O (2004) A monetary vector error correction model of the Euro area and implications for monetary policy. *Empir Econ* 29:553–574
- Hurtado S (2014) DSGE models and the Lucas critique. *Econ Model* 44:S12–S19
- IMF International Monetary Fund (2013) *Key aspects of macroprudential policy*. Background paper, IMF Policy Paper
- Ivanov V, Kilian L (2012) A practitioners guide to lag order selection for VAR impulse response analysis. In: Mizraeh B (ed) *Studies in nonlinear dynamics and econometrics*, vol. 9(1). De Gruyter, pp. 1–36
- Jiménez G, Ongena S, Peydró JL, Saurina J (2017) Macroprudential policy, countercyclical bank capital buffers, and credit supply: evidence from the Spanish dynamic provisioning experiments. *J Political Econ* 125:2126–2177
- Jiménez G, López JA, Saurina J (2010) How does competition impact bank risk-taking? *Documentos de Trabajo*, 1005, Banco de España
- Johansen S (1988) Statistical analysis of cointegration vectors. *J Econ Dyn Control* 12:231–254
- Juselius K (2006) *The cointegrated VAR model: methodology and applications*. Oxford University Press, Oxford, New York
- Keister T, McAndrews J (2009) Why are banks holding so many excess reserves? *Federal Reserve Bank of New York Staff Reports*, Staff Report 380

Kilian H, Lutkepohl H (2017) Structural vector autoregressive analysis. Cambridge books, Cambridge University Press

Kim J (2018) Bank competition and financial stability: liquidity risk perspective. *Contemp Econ Policy* 36:337–362

Kiyotaki N, Moore J (2018) Inside money and liquidity. Economics Department Working Paper 8, Princeton University

Koopman G-J (2011) Stability and competition in EU banking during the financial crisis: the role of state aid control. *Compet Policy Int* 7:8–21

Kuttner KN, Mosser PC (2002) The monetary transmission mechanism: some answers and further questions. Federal Reserve Bank New York, Economic Policy Review (May)

Kwiatkowski D, Phillips PCB, Schmidt YC, Shin P (1992) Testing the null hypothesis of stationarity against the alternative of a unit-root. *J Econom* 54:159–178

Ljungqvist L, Sargent TJ (2018) Recursive macroeconomic theory, 4th edn. The MIT Press

Lucas R (1980) Equilibrium in a pure currency economy. *Econ Inq* 18:203–220

Lucas R (1982) Interest rates and currency prices in a two-country world. *J Monetary Econ* 10:335–359

Lucas R (1990) Liquidity and interest rates. *J. Econ. Theory* 50:237–264

Marimon R, Nicolini JP, Teles P (2003) Inside–outside money competition. *J Monetary Econ* 50:1701–1718

Mas-Colell A, Whinston MD, Green JR (1995) Microeconomic theory. Oxford University Press

Mendicino C, Nikolov K, Rubio-Ramirez J, Suarez J, Supera D (2021) Twin defaults and bank capital requirements. ECB WP 2014

Mendoza EG, Terrones ME (2014) An anatomy of credit booms and their demise. Central banking, analysis, and economic policies book series. In: Diaz MF, Raddatz CE, Reinhart CM (eds) Capital mobility and monetary policy, 1st edn, vol 18. Central Bank of Chile, pp. 165–204

Minsky H (1982a) Can it happen again? Essays on instability and finance. M.E. Sharpe, Inc., Armonk, NY

Minsky H (1982b) Debt–deflation processes in today’s institutional environment. *Banca Naz Lav Q Rev* (December)

Monnet C, Weber WE (2001) Money and interest rates. *Fed Reserve Bank Minneapolis Q Rev* (Fall):2–13

Murota R, Ono Y (2015) Fiscal policy under deflationary gap and long-run stagnation: reinterpretation of Keynesian multipliers. *Econ Model* 51:596–603

Nagel S, Purnanandam A (2020) Banks risk dynamics and distance to default. *Rev Financ Stud* 33:2421–2467

Palley TI (2002) Endogenous Money: What It Is and Why It Matters. *Metroeconomica* 53:152–180

Palley TI (2013) Horizontalists, verticalists, and structuralists: the theory of endogenous money reassessed. *Rev Keynes Econ* 4:406–424

Pesaran MH, Shin Y, Richard J (2000) Structural analysis of vector error correction models with exogenous I(1) variables. *J Econom* 97:293–343

Ross CP, Wiggins R, Metrick A (2019) European Central Bank Tools and Policy Actions A: open market operations, collateral expansion and standing facilities. *Yale School Manag J Financ Crises* 1:57–81

Rünstler G et al (2018) Real and financial cycles in EU countries—stylised facts and modelling implications. European Central Bank, Occasional Paper Series 205

Schularick M, Taylor AM (2012) Credit booms gone bust: monetary policy, leverage cycles, and financial crises, 1870–2008. *Am Econ Rev* 102:1029–61

Stokey NL, Lucas RE, Prescott EC (1984) Recursive methods in economic dynamics. Harvard University Press, Cambridge

Sims CA (1980) Macroeconomics and reality. *Econometrica* 48:1–48

Stracca L (2013) Inside money in general equilibrium: does it matter for monetary policy. *Macroecon Dyn* 17:563–590

Toda HY, Yamamoto T (1995) Statistical inference in vector autoregressions with possibly integrated processes. *J Econom* 66:225–250

von Peter G (2005) Debt–deflation: concepts and a stylised model. BIS Working Papers 176

Weber AA, Gerke R, Worms A (2009) Has the monetary transmission process in the euro area changed? Evidence based on VAR estimates. BIS Working Papers 276

## Acknowledgements

This article was largely completed while PJGD was visiting the Department of Economics of the European University Institute (EUI) from January 2023 to May 2023. The authors express their gratitude to the EUI for providing research facilities and access to internal scientific meetings. PJGD acknowledges financial support from: Spanish Agencia Estatal de Investigación-Ministerio de Ciencia e Innovación (research project PID2020-113554GB-I00/AEI/10.13039/501100011033); University of Valladolid Research Group on Dynamic Optimization, Mathematical Finance and Recursive Utility; and University of Valladolid-Bank of Santander 2023 Mobility Aids for Researchers. Professional assistance for manuscript preparation from Alan F. Hydns, B.A. Dip. TEFL, is highly appreciated.

## Author contributions

PJGD and TP contributed equally to this work.

## Competing interests

The authors declare no competing interests.

## Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

## Informed consent

This research involves no procedures for which informed consent is required.

## Additional information

**Supplementary information** The online version contains supplementary material available at <https://doi.org/10.1057/s41599-023-02030-0>.

**Correspondence** and requests for materials should be addressed to Pedro J. Gutiérrez-Diez.

**Reprints and permission information** is available at <http://www.nature.com/reprints>

**Publisher’s note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Open Access** This article is licensed under a Creative Commons

Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2023, corrected publication 2024