WORKING paper

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Downward Interest Rate Rigidity

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ABSTRACT

Empirical evidence suggests that bank lending rates are downward rigid: banks tend to adjust their rates more slowly and less completely to short-term market rates decreases than to increases. We investigate the macroeconomic consequences of this downward interest rate rigidity by introducing asymmetric bank lending rate adjustment costs in a macrofinance dynamic stochastic general equilibrium model. Calibrating the model to the euro area economy, we find that the difference in the initial response of GDP to positive and negative economic shocks of similar amplitude can reach up to 25%. This means that a central bank would have to cut its policy rate much more to obtain a symmetric medium-run impact on GDP. We also show that downward interest rate rigidity is stronger when policy rates are stuck at their effective lower bound, further disrupting monetary policy transmission. These findings imply that neglecting asymmetry in retail interest rate adjustments may yield misguided monetary policy decisions.

Keywords: Downward Interest Rate Rigidity, Asymmetric Adjustment Costs, Banking Sector, DSGE Model, Euro Area.

JEL classification: E32, E44, E52.

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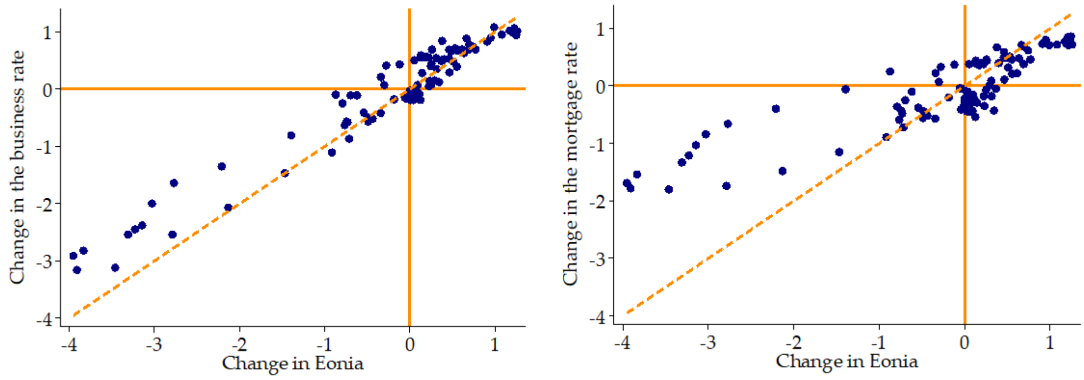
Non-Technical Summary

Standard practice in structural macroeconomic modelling is to assume that retail bank interest rates adjust similarly upward and downward following economic shocks. However, empirical evidence from banking data suggests that bank lending rates (BLRs) are downward rigid. As shown by the Figure below, banks tend to adjust their rates slowly and incompletely in response to monetary policy easing, while they do increase them fairly quickly and rather proportionally as policy rates increase.

Scatter plots of year-on-year changes in Eonia and bank lending rates in the euro area (%)



What are the macroeconomic effects of such a downward interest rate rigidity? What are the consequences of neglecting it in standard macroeconomic modelling?

In this paper, we address this question by introducing asymmetric bank lending rate adjustment costs in a macrofinance dynamic stochastic general equilibrium (DSGE) model. The model is calibrated on euro-area data, by matching in particular the empirical (low) volatility and (significantly positive) skewness of year-on-year changes in business and mortgage lending rates.

We propose a comparison of the effects of several structural shocks on the real economy in the presence of such an interest rate asymmetry. We find that the difference in the initial response of GDP to positive and negative shocks of similar amplitude can reach up to 25%. This implies that a central bank would have to cut its policy rate much more to obtain a medium-run impact on GDP that would be symmetric to the impact of a shock implying a policy rate increase. This refers to the famous "string" metaphor: employing tight monetary policy to curb excess demand and inflation is like pulling on a string – it works well. However, attempting to stimulate the economy with loose policy during a downturn is like pushing on a string – it is not very effective. In this vein, we examine the effort that the central bank could make to compensate for the downward rigidity of BLRs. We find that a central bank would have to decrease its policy rate by 20% to 100% more to yield a medium-run impact on GDP that is symmetric to the impact of a positive monetary shock.

Finally, by investigating the post-2012 period, we show that downward interest rate rigidity is even stronger when policy rates are stuck at their effective lower bound. This is mainly due to the existence of a lower bound on deposit rates, but also to a lower bound on BLRs stemming from frictions that are intrinsically related to banks' business model. In Europe, a weaker intermediation margin could hardly be compensated by other sources of profitability because of overcapacity (low cost-efficiency) and insufficiently diversified structure of revenues (weak income-generation capacity). Hence, deterioration in profitability may induce a lower bound on BLRs, which reduces the effectiveness of monetary policy. This deterioration of the pass-through of monetary policy in periods of ultra-low interest rates justifies a strong reaction to negative shocks. For example, this supports the large-scale unconventional measures implemented by central banks in 2020 to counteract the economic impact of the Covid-19 pandemic.

More generally, given its macroeconomic consequences, neglecting downward interest rate rigidity in macroeconomic models may yield misguided monetary policy decisions.

Rigidité à la baisse des taux d'intérêt

RÉSUMÉ

Les analyses empiriques suggèrent que les taux d'intérêt sur les prêts bancaires sont rigides à la baisse : les banques ont tendance à répercuter plus lentement et moins que proportionnellement les baisses de taux d'intérêt de marché sur leurs taux débiteurs qu'elles ne répercutent les hausses de taux. Nous étudions les conséquences macroéconomiques de cette rigidité à la baisse des taux d'intérêt en introduisant des coûts d'ajustement asymétriques des taux des prêts bancaires dans un modèle d'équilibre général dynamique stochastique. En étalonnant ce modèle sur la zone euro, nous trouvons que la différence de réponse initiale du PIB à des chocs positifs et négatifs de même amplitude peut atteindre jusqu'à 25%. Cela signifie que la banque centrale devrait davantage réduire son taux directeur pour obtenir un impact à moyen terme sur le PIB équivalent à l'impact d'une hausse de taux. Nous montrons également que la rigidité à la baisse des taux d'intérêt est plus forte lorsque les taux directeurs sont à leur borne inférieure effective, ce qui affaiblit encore plus la transmission de la politique monétaire. Ces résultats indiquent que négliger l'asymétrie dans l'ajustement des taux d'intérêt bancaires peut conduire à des recommandations de politique monétaire erronées.

Mots-clés : rigidité à la baisse des taux d'intérêt, coûts d'ajustement asymétriques, modèles DSGE, zone euro.

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1. Introduction

Standard practice in structural macroeconomic modeling is to assume that retail bank interest rates adjust similarly upward and downward following economic shocks. However, empirical evidence from banking data suggests that lending rates are downward rigid. In particular, banks tend to adjust their rates more slowly and less completely in response to monetary policy easing, while they do increase them fairly quickly and by roughly the same proportion in response to a tightening of the operational targets of central banks. What are the effects of neglecting such a rigidity in an economy where the external financing of households and firms mainly consists of loans originated and held by banks?

In this paper, we address this question by introducing asymmetric bank lending rate adjustment costs in a macrofinance dynamic stochastic general equilibrium (DSGE) model to reveal the macroeconomic consequences of downward interest rate rigidity. In particular, we seek to assess to what extent the non-linear dynamics of bank rates may induce asymmetry in the response of key real variables (lending, consumption, investment, and output) to identical shocks of opposite signs.

There are several theoretical motivations for explaining downward interest rate rigidity at the bank level. The first, and undoubtedly the most often put forward, relates to *bank concentration*, which leads to oligopolistic behaviors (Berger and Hannan, 1989 Hannan and Berger, 1991 Neumark and Sharpe, 1992).[1] Banks in concentred markets can postpone or at least partially renounce lower lending rates to increase their profit margins. In the same vein, *customer switching costs*, i.e., the costs a consumer pays as a result of switching financial institutions, give banks an additional degree of market power (Klemperer, 1987, Klemperer, 1995, Calem and Mester, 1995).[2] Switching costs generate a lock-in effect and make the demand for credit rather inelastic. In such a context, banks have an incentive to increase their mark-up by reducing their lending rates either incompletely or slowly following a downward trend in market rates. In contrast, when market rates increase, banks may more quickly raise their lending rates, thereby maintaining or increasing their mark-up. This is even more likely if banks face *adjustment costs* like menu costs, i.e., the costs associated with advertising new price lists, communicating with customers, etc. (Rotemberg and Saloner, 1987). While banks' menu costs may be offset by higher loan returns when lending interest rates rise, lowering lending rates implies both adjustment costs and lower interest income. Hence, adjustment costs can restrain banks from making frequent price adjustments and can imply sign-driven asymmetries.[3] Another argument is based on

[1] In line with this argument, our structural model embeds monopolistically competitive banks.

[2] Switching costs are the results of (i) administration fees (i.e., fees charged to open or close a bank account and costs related to the renegotiation of the terms of the outstanding debt) as well as (ii) the loss of some relationship-based benefits in case of changing lenders (Berger and Udell, 1992).

[3] The non-bank literature suggests several reasons for which menu costs can lead to asymmetric price adjustment (Caballero and Engel, 1993, Ball and Mankiw, 1994, Tsiddon, 1993 and Madsen and Yang, 1998). First, following negative shocks, firms can keep their prices constant (and save on their menu costs) because the aggregate inflation will automatically reduce

collusive agreements: banks may be more reluctant to lower than raise loan rates because it is more likely to be interpreted as cheating behaviour that could trigger a costly price war (Rotemberg and Saloner, 1986, Fershtman and Pakes, 2000). In the best case, they have to delay interest rate revisions until other banks understand that the change is simply a response to modifying market conditions and not a violation of the collusive agreement. A last explanation for downward lending rate rigidity builds on the *"reverse" adverse selection* theory developed by Ausubel (1991). According to this view, lenders should be reluctant to cut lending rates because this is likely to attract high-risk credit and card holders who "fully intend to borrow", i.e., who plan to fully utilize their credit lines and accumulate more debt. Note that most of these theoretical causes of rigidity are relatively close to the explanations provided in the literature on sticky prices. In the following, we do not favor one explanation over another. Instead, we use a modeling shortcut that encompasses all of these theoretical justifications and allows us to focus on their aggregate effects.

Assessing the macroeconomic consequences of downward interest rate rigidity requires a structural macrofinance model that has the advantages of (i) explicitly formalizing the behavior of each economic agent to identify the channels through which shocks affect the economy and (ii) dealing rigorously with the endogeneity issue between policy and retail rates, which is rarely addressed in the literature on interest rate pass-through. Hence, we consider a DSGE model *à la* Gerali et al. (2010), as it represents a good compromise between realism and flexibility. First, it combines a neoclassical growth core with several shocks and frictions that have been successful in providing an empirically plausible account of key macroeconomic variables (see, e.g., Smets and Wouters, 2007; Justiniano et al., 2010). Second, the model includes credit frictions and borrowing constraints as in Iacoviello (2005) and, more importantly, an imperfectly competitive banking sector that offers intuitive interactions between the different interest rates. We augment this frictional banking sector to allow for asymmetric adjustment costs. More precisely, we introduce a linex function that implies larger costs for decreasing interest rates than for increasing them by the same size.[4] This modeling device captures in a simple but effective way the different theoretical arguments highlighted above and the evidence from banking data. Parameters of this function are chosen to match the observed volatility and skewness of the year-on-year changes in business and mortgage lending rates. To capture the nonlinearities coming from asymmetric adjustment costs, the model is solved by second-order perturbation methods by applying the pruning approach of Kim et al. (2008). This technique is recommended to guarantee stability of

their relative prices for free. This option does not exist face to positive shocks. Second, the magnitude of shocks is important to generate more or less asymmetry. For instance, the strategy of keeping prices constant can be optimal in response to a small change in nominal demand because the loss associated with this strategy is second order. Third, the value of the elasticity of demand impacts the degree of asymmetry. When firms face a low price elasticity of demand, prices become downwardly sticky due to high revenue loss from lowering its price in the wake of adverse demand shocks.

[4]Such a convex function is used by Kim and Ruge-Murcia (2009) and Abbritti and Fahr (2013) to model asymmetric wage adjustments.

approximations up to the second order of accuracy by "pruning" the terms of the solution that can generate instability.

Therefore, we propose a comparison of the effects of several structural shocks on the real economy in the presence of interest rate asymmetry. Calibrating the model to the euro area economy, we find that the difference in the initial response of GDP to positive and negative shocks of similar amplitude can reach up to 25%. This implies that a central bank would have to cut its policy rate much more to obtain a medium-run impact on GDP that would be symmetric to the impact of a shock implying a policy rate increase. This refers to the famous "string" metaphor: Employing tight monetary policy to curb excess demand and inflation is like pulling on a string – it works well. However, attempting to stimulate the economy with loose policy during a downturn is like pushing on a string – it is not very effective.[5] For instance, we show that a central bank would have to decrease its policy rate by 20% to 100% more to yield a medium-run impact on GDP that is symmetric to the impact of a positive monetary shock. We also show that downward interest rate rigidity is stronger when policy rates are stuck at their effective lower bound, due to frictions that are intrinsically related to banks' business model, further disrupting monetary policy transmission. As a result, neglecting downward interest rate rigidity may bring about misguided monetary policy decisions.

While a vast empirical literature has sought to estimate pass-through using econometric time series models, few studies have investigated the effects of interest rate asymmetry on the real economy in a structural framework. DeLong and Summers (1988) and Cover (1992) are among the first to report asymmetric effects of monetary policy, using a simple two-stage estimation process based on an empirical model and innovations to the money growth rate as a measure of the stance of monetary policy. They find that negative innovations to money growth have a significant negative effect on US output, whereas positive innovations do not. Studies that have followed mainly extended these authors' econometric methodology but still neglect the endogeneity issue of the policy rate or propose statistical descriptions without assessment of the macroeconomic effects of asymmetries. Recent quantitative macroeconomic models that incorporate different financial frictions to exploit the amplification and propagation mechanism of borrowing constraints can match various business cycle properties. However, they are unable to generate asymmetric effects of monetary policy on economic

[5]The string metaphor was used in a House Committee on Banking and Currency in 1935, in the context of the Great Depression. Federal Reserve Governor Marriner Eccles: "*Under present circumstances there is very little, if anything, that can be done.*". Congressman T. Alan Goldsborough: "*You mean you cannot push a string*". Governor Eccles: "*That is a good way to put it, one cannot push a string. We are in the depths of a depression and [...], beyond creating an easy money situation through reduction of discount rates and through the creation of excess reserves, there is very little, if anything that the reserve organization can do toward bringing about recovery*". Tenreyro and Thwaites (2016) and Barnichon et al. (2017), among others, discuss recent developments on the asymmetric effects of monetary policy, which are conditional on the business cycle. Our contribution rather builds on bank behavior as a source of asymmetry.

aggregates.[6] These models implicitly assume that the credit constraints faced by borrowers are always binding. As a consequence, the resulting decision rules act as if agents behave linearly and the economy responds symmetrically to shocks. An exception is Santoro et al. (2014), who develop a model where household utility depends on consumption deviations from a reference level, below which loss aversion is displayed. Loss-averse consumption preferences imply state-dependent degrees of real rigidity and elasticity of intertemporal substitution in consumption that generate competing effects on the responses of output and inflation following a monetary innovation. In their framework, the different impacts of monetary policy shocks are explained by changes in the preferences of the public but not by frictions in the banking sector. Hence, to the best of our knowledge, our contribution is the first to model an asymmetric monetary policy pass-through and to assess its macroeconomic consequences.

In the remainder of the paper, Section 2 documents the empirical regularities on retail interest rates that motivated the paper. Section 3 describes the DSGE model with both sluggish and asymmetric adjustment of bank lending rates. Section 4 presents the calibration procedure and the model evaluation. Section 5 assesses the macroeconomic effects of downward interest rate rigidity. Section 6 analyzes the pass-through of easing through unconventional monetary policies, including negative policy rates. A final section concludes.

2. Bank lending rate asymmetry: Empirical facts

The empirical analysis conducted in this section relies on aggregated banking data for the euro area. We focus on lending business rates to nonfinancial companies and lending rates to households for house purchase. In addition, since the ECB implements monetary policy by steering the very short-term interest rates in the interbank money market (market rates herefafter), we focus on Eonia, considered as its operational target. As lending rates are sticky in the short run, we consider year-on-year changes to properly capture their dynamics and the pass-through of monetary policy. The monthly data series come from the European Central Bank (ECB) Statistical Data Warehouse and are available from January 1998 to December 2018, except for mortgage rates, which are not available before January 2003 and for Eonia, which starts in January 1999 (full details are provided in Appendix A). Our initial investigation is carried out on the pre-2012 period. In June 2012, the ECB decided to lower its policy rates by 25 basis points, bringing the deposit facility rate to 0 percent, which was then left unchanged for almost two years until going into negative territory in June 2014. While our analysis mainly focuses on a "normal" context of positive interest rates, the dynamics and pass-through of interest rates when they are at their effective lower bound, i.e., over 2012–2018, deserve a specific

[6] See among others, Carlstrom and Fuerst (1997), Bernanke et al. (1999), Iacoviello (2005), Iacoviello and Neri (2010), Gertler and Karadi (2011), or Carlstrom et al. (2017).

analysis, which is carried out in Section 6. For comparative purposes, we also examine the dynamics of interest rates in the United States over a long period (1975–2018), as well as in France and Germany (1998–2012). Importantly, note that we did not find evidence of asymmetry in the evolution of banks' deposit rates (see details in Appendix B). Therefore, we focus in the following on the asymmetric dynamics of lending rates.

2.1. **Fact 1: The downward rigidity of bank lending rates.** A simple method of assessing asymmetric adjustments of a variable consists of examining its skewness. Generally speaking, a positive skewness indicates downward rigidity, as it means that a variable – in our case, bank lending rates (BLRs hereafter) – rises faster above its mean, while reductions below the mean occur in smaller steps.

TABLE 1. Skewness of year-on-year changes in bank lending rates and market rates

Interest rate	Euro area	France	Germany	United States
Bank lending rate: Business	0.45	0.61	0.45	0.26
	[0.04]	[0.00]	[0.04]	[0.03]
Bank lending rate: Mortgage	-	0.64	0.56	0.35
	-	[0.00]	[0.01]	[0.00]
Market rate	0.13	-	-	0.13
	[0.57]	-	-	[0.29]

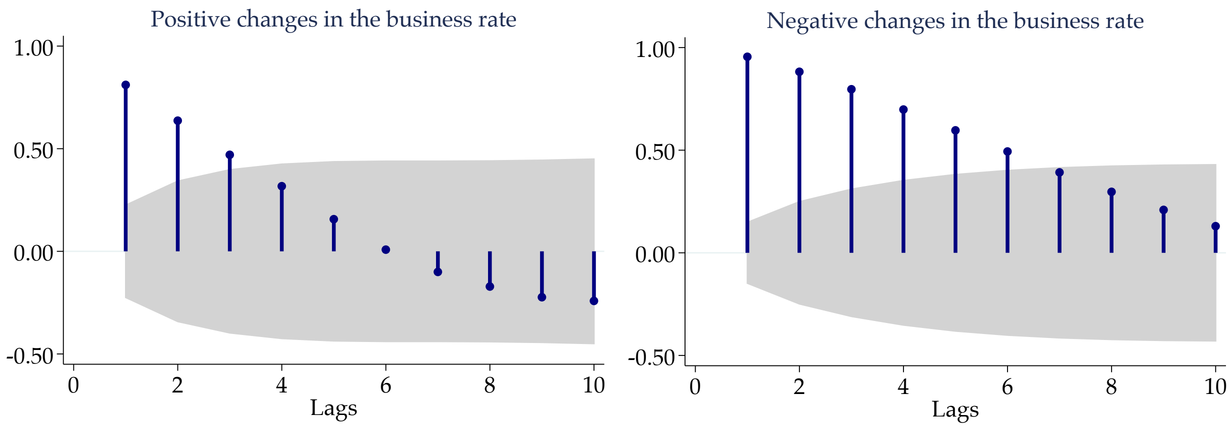
Note: The market rate corresponds to Eonia for the euro area and to the effective federal funds rate for the United States. Skewness is computed over the period 1998-2007 for the euro area, France and Germany. It is computed over 1975-2007 for the United States. Mortgage rates for the euro area are ignored because they are not available before 2003. P-values for the null hypothesis of no skewness are in square brackets.

Table 1 shows that year-on-year changes in business and mortgage BLRs are positively skewed in the euro area.[7] Indeed, we obtain a skewness of business BLR of 0.45 in the euro area, 0.61 in France and 0.45 in Germany. The skewness is even higher for mortgage rates, with values of 0.65 for France and 0.56 for Germany. This first empirical fact is not specific to the euro area; we also find a positive skewness in the United States over a longer period, from 1975 to 2007. Notice that this asymmetry is specific to BLRs as the skewness of market rates in the euro area and in the United States is not significantly different from zero, as shown in the last row of Table 1.

Another method of assessing asymmetric adjustment is to consider the autocorrelation functions of BLRs and to compare their dynamics according to whether the year-on-year change in lending rates (denoted by ΔBLR) is positive or negative. Figure 1 shows a stronger autocorrelation when ΔBLR to firms decrease in comparison to when they increase. Again, this suggests more downward than upward sluggishness.

[7] This is observed on normal times, i.e., apart from the financial crisis. Obviously, if we introduce the financial crisis in our sample, the statistics would be biased because the period 2008-2010, in particular, is characterized by successive huge cuts in the policy rate, as indicated in Table C1 in Appendix C. The distribution of BLRs would tend to be negatively skewed due to this exceptional event distorting the usual characteristics of lending rates. Section 6 addresses the post global financial crisis period.

FIGURE 1. Autocorrelation functions of euro-area business bank lending rates



Note: The gray areas represent Bartlett's formula for the moving-average model of order q 95% confidence bands.

This asymmetric autoregressive behavior can be tested by using a self-exciting threshold autoregressive (SETAR) model. This class of model has proven to provide good performance in allowing different relationships to apply over separate regimes (Hansen (1996, 2000)). Let $I(.)$ be a dummy variable that is equal to 1 if $\Delta BLR_{t-1} > \varsigma$ and 0 otherwise, with ς is the endogenous threshold parameter. We obtain the following estimate:

$$\begin{aligned} \Delta BLR_t = & \{\underset{(0.014)}{0.006} + \underset{(0.141)}{0.716} \ \Delta BLR_{t-1}\} \left[1 - I\left(\Delta BLR_{t-1} > \varsigma\right)\right] \\ & + \{\underset{(0.005)}{0.006} + \underset{(0.096)}{0.251} \ \Delta BLR_{t-1}\} \left[I\left(\Delta BLR_{t-1} > \varsigma\right)\right] + \varepsilon_t \end{aligned} \tag{1}$$

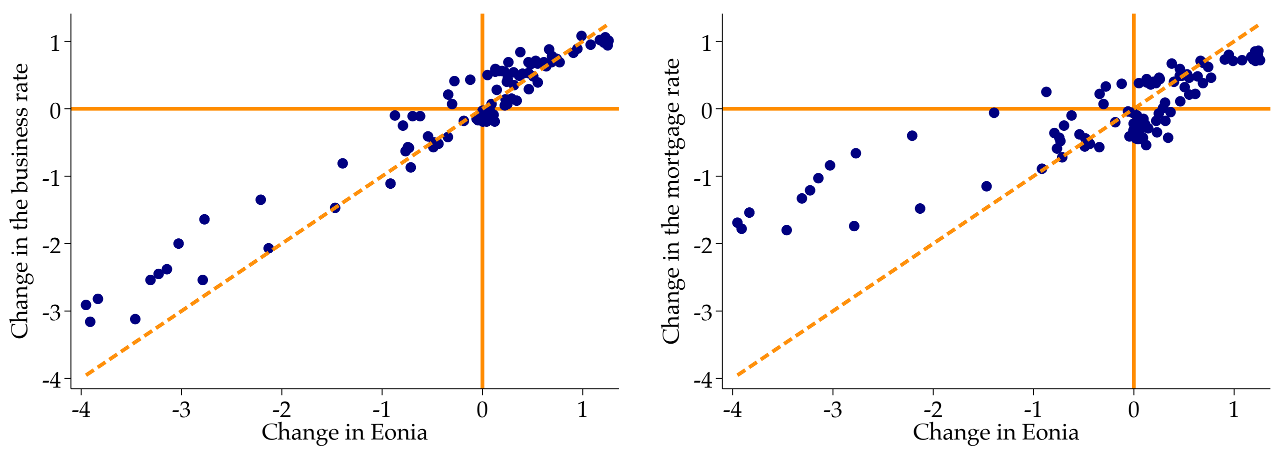
where ε_t a white-noise error term with constant variance and heteroskedasticity-consistent standard errors in parentheses. First, the hypothesis of linearity of the dynamics of BLRs, tested with the LM statistics suggested by Hansen (1996), is rejected at the 1% level.[8] Second, regime switching is found around a threshold that is very close to zero ($\hat{\varsigma} = -0.01$). Third, the downward persistence of the BLR is found to be approximately three times higher than its upward persistence (0.72 versus 0.25). This confirms the former intuition on the downward inertia of BLRs. Similar results are found for France, Germany and the United States (see Table C2 in Appendix C).

Finally, we can note that the observed downward rigidity of bank lending rates is not as strong as the downward rigidity usually found for wages and prices. Indeed, Abbritti and Fahr (2013) find a higher skewness for the annual growth rate of nominal and real wages, close to 0.9, as well as for the annual growth rate of the GDP deflator, close to 0.7. Nonetheless, the downward rigidity of BLRs has more direct and crucial implications for the transmission of monetary policy.

[8]Estimates and tests are run over the period 1999-2012. LM Sup, Exp LM and LM Ave statistics for the null hypothesis of no threshold effects are equal to 15.02, 5.82 and 10.59, respectively, with all p-values equal to 0.00. Tests are based on 5000 draws.

2.2. **Fact 2: Asymmetric interest rate pass-through of monetary policy.** The asymmetric interest rate pass-through of monetary policy is an important corollary of the downward rigidity of BLRs. Figure 2 reports the scatter points of the changes in BLRs and Eonia over 2004-2012. This period is guided by both the data availability of mortgage rates and the exclusion of the period of effective lower bound for the short-term market rate. We observe that the scatter points deviate significantly from the 45-degree line (which would imply a one-to-one response of BLRs to Eonia), especially in the area of negative changes. This suggests that BLRs respond more strongly (and possibly more quickly) to market rate increases than to market rate cuts. Further evidence on the BLR-market rate nexus shows notably that BLRs did not decrease as strongly as the market rate in the wake of the global financial crisis (see Table C3 in Appendix C). A similar asymmetric monetary policy pass-through is found for the United States over a longer period (see Appendix D).

FIGURE 2. Scatter plots of year-on-year changes in Eonia and bank lending rates in the euro area (percent)



Note: The scatter points represent year-on-year changes in Eonia and bank lending rates over 2004-2012.

This is in line with the conclusions of the empirical works of Mojon (2000) and Sander and Kleimeier (2004) for the euro area, and Mester and Saunders (1995) for the United States. Other studies have obtained more mixed results.[9] More generally, this empirical literature does not properly address the critical issue of the endogeneity of short-term market rates (as a proxy for monetary policy rates). These rates are assumed to be exogenous when estimating the pass-through, while central banks adjust the stance of monetary policy according to the effectiveness of their transmission to BLRs. Moreover, empirical studies suffer from model misspecifications: they usually test for asymmetric (short- and long-run) elasticity of BLRs to market rates, whereas it is the autoregressive process of BLRs itself that evolves asymmetrically, as shown above. These limitations call for an analysis based on a structural approach, capable of reproducing the two stylized facts highlighted in this section.

[9]See, for instance, Kwapil and Scharler (2010) and Belke et al. (2013).

3. The structural model

In this section, we describe the structural model we use to evaluate the macroeconomic consequences of downward interest rate rigidity. First, we introduce asymmetric costs of lending rate adjustment in the DSGE model developed and estimated by Gerali et al. (2010), as it represents a good compromise between flexibility and realism. After a brief overview of the framework, we present the banking sector in detail. The description of the remaining parts of the model is relegated to Appendix E, and all the equilibrium conditions are proposed in Appendix F.

3.1. **Model overview.** The economy is inhabited by heterogeneous households, entrepreneurs, and monopolistically competitive firms and banks.
Households maximize a separable utility function in consumption, labor effort and housing over an infinite life horizon. Consumption appears in the utility function relative to a time-varying external habit that depends on past aggregate consumption. Housing is in fixed supply and is traded among households. Households can be patient or impatient, with the discount factor associated with the future utility of the patient households being higher than that of the impatient households. The existence of these two types of households allows positive financial flows to be generated in equilibrium: patient households save by placing deposits in banks, and impatient households borrow from banks, subject to a collateral (housing stock) constraint. Households supply their differentiated labor services through unions that set nominal wages to maximize members' utility, subject to downward sloping demand and quadratic adjustment costs. Labor services are sold to competitive employment agencies, which assemble these services into a homogeneous labor input and then sell it to entrepreneurs.

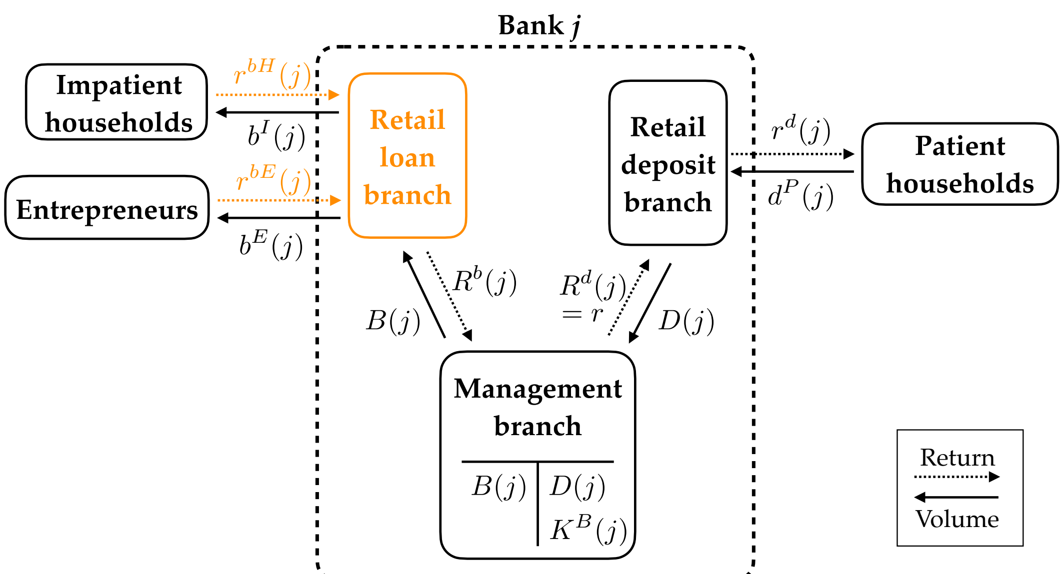
Entrepreneurs own competitive firms that produce a homogeneous intermediate good using labor services, supplied by employment agencies, and capital, bought from capital-good producers. The introduction of variable capital utilization implies that the capital stock can be used more or less intensively according to some cost schedule, as the rental price of capital changes. Entrepreneurs obtain loans from banks, the amount of which is constrained by the value of entrepreneurs' collateral, i.e., the value of the stock of physical capital they hold.

On the production side, there are also monopolistically competitive capital-good producers and retailers. Capital-good producers combine old undepreciated capital, acquired from the entrepreneurs, and final goods, purchased from the retailers, to create new productive capital. Transforming final goods into capital involves quadratic adjustment costs. The producers sell the new capital back to entrepreneurs. The introduction of this sector is a simple way to make explicit the expression for the price of capital that enters entrepreneurs' borrowing constraint. Finally, the monopolistically competitive retailers buy intermediate goods from the entrepreneurs and differentiate them subject to nominal rigidities.

3.2. **The banking sector.** In this section, we expound on the Gerali et al. (2010) frictional banking sector in which we introduce asymmetric adjustment costs associated with changing loan rates.

There is a continuum of monopolistically competitive banks, indexed by $j \in [0, 1]$, which supply two types of one-period financial instruments, namely, saving contracts (deposits) and borrowing contracts (loans). Each bank must satisfy a balance sheet identity such that loans $B_t(j)$ are equal to deposits $D_t(j)$ plus bank capital $K_t^B(j)$. In addition, banks must comply with an exogenous target for their capital-to-assets ratio, which can be likened to a regulatory capital requirement. Deviations from this target imply quadratic costs. In this way, bank capital has a key role in determining credit supply conditions in the model. As banks slowly accumulate capital through retained earnings (no equity issuance), this creates a feedback loop between the real side and the financial side of the economy. For the sake of presentation, it is convenient to consider bank j as a group made up of three branches: a loan branch, a deposit branch and a management branch. A schematic of the banking sector is proposed in Figure 3. We elaborate the problems faced by these branches next.

FIGURE 3. Schematic of the banking sector



Note: r^i, where $i = \{bH, bE, d\}$, denotes returns received from (paid to) final borrowers (deposit holders). R^d and R^b denote internal returns. r is the policy rate.

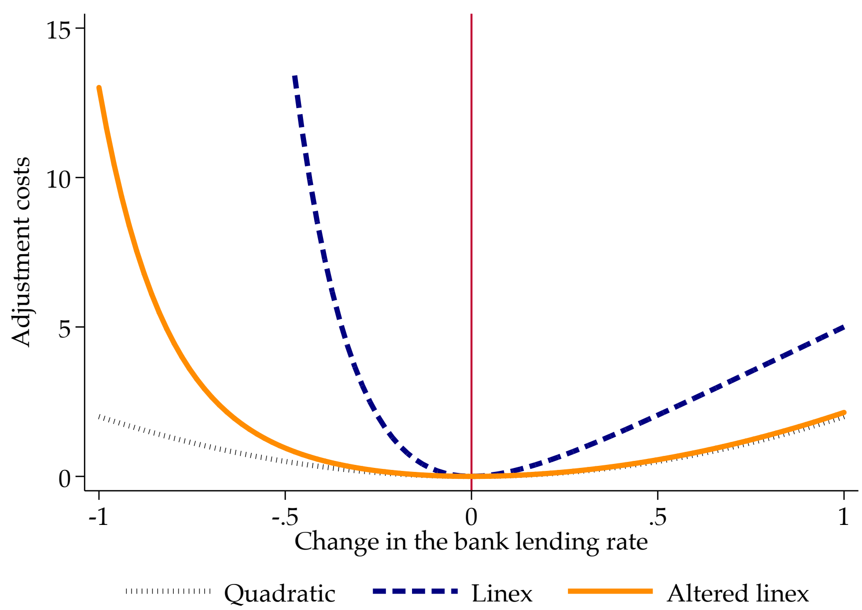
3.2.1. *The retail loan branch.* Retail loan branches operate in monopolistic competition. They obtain global loans $B_t(j)$, in real terms, from the management branch at rate $R_t^b(j)$, differentiate them at no cost, and resell them to households and entrepreneurs, with different markups. They maximize their expected discounted profits by choosing the interest rates on loans offered to households $r_t^{bH}(j)$ and to entrepreneurs $r_t^{bE}(j)$, subject to the costs of changing these rates.

To capture the downward interest rates rigidity highlighted in the empirical analysis, we introduce an adjustment costs function that is convex and asymmetric, such as it is more costly for banks to cut than to increase bank lending rates. More precisely, we assume an altered linex cost function as in Fahr and Smets (2010) and Abbritti and Fahr (2013):

$$\mathcal{A}_{bs}\left(\frac{r_t^{bs}(j)}{r_{t-1}^{bs}(j)}\right) = \frac{\kappa_{bs}}{2}\left(\frac{r_t^{bs}(j)}{r_{t-1}^{bs}(j)} - 1\right)^2 \\ + \frac{1}{\psi_{bs}^2}\left\{\exp\left[-\psi_{bs}\left(\frac{r_t^{bs}(j)}{r_{t-1}^{bs}(j)} - 1\right)\right] + \psi_{bs}\left(\frac{r_t^{bs}(j)}{r_{t-1}^{bs}(j)} - 1\right) - 1\right\}, \tag{2}$$

for $s = \{E, H\}$. The parameter κ_{bs} determines the degree of convexity and ψ_{bs} the degree of asymmetry in adjustment costs around their steady-state value. This functional form nests the quadratic function in the limit, as $\psi_{bs} \to 0$. Figure 4 displays a comparison between the quadratic, the original linex proposed by Varian (1974) and the altered-linex specifications. It illustrates a desirable property in our context: the altered-linex function allows the costs of interest rate increases to be unaltered relative to the symmetric (quadratic) case, unlike a standard linex function that distorts both sides. Such costs imply a smooth and asymmetric adjustment of mortgage and business lending rates.

FIGURE 4. Quadratic, linex and altered linex adjustment cost functions



Last, adjustment costs are assumed to be proportional to aggregate returns on loans ($r_t^{bs} b_t^s$). Thus, the loan retail branch's problem is to solve

$$\max_{\{r_t^{bH}(j), r_t^{bE}(j)\}} \mathrm{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[\sum_{s=E,H}\left(r_t^{bs}(j) b_t^s(j) - \mathcal{A}_{bs}\left(\frac{r_t^{bs}(j)}{r_{t-1}^{bs}(j)}\right) r_t^{bs} b_t^s\right) - R_t^b(j) B_t(j)\right], \tag{3}$$

subject to Dixit-Stiglitz loan demand curves

$$b_t^s(j) = \left(\frac{r_t^{bs}(j)}{r_t^{bs}}\right)^{-\varepsilon_t^{bs}} b_t^s, \tag{4}$$

with $B_t(j) = b_t^H(j) + b_t^E(j)$, $r_t^{bs} = [\int_0^1 r_t^{bs}(j)^{1-\varepsilon_t^{bs}} dj]^{\frac{1}{1-\varepsilon_t^{bs}}}$, and where b_t^s is the aggregate loans in the economy, with $s \in \{E, H\}$. Units of loan contracts bought by households and entrepreneurs are a composite constant elasticity of substitution basket of differentiated financial products with elasticity terms equal to $\varepsilon_t^{bH} > 1$ and $\varepsilon_t^{bE} > 1$. The terms are assumed to be stochastic to introduce an exogenous component in credit market spreads. It is assumed that banks take the patient households' (who are their only owners) stochastic discount factor $\Lambda_{0,t}^P$. Imposing a symmetric equilibrium (dropping the j index), the first-order conditions for lending rates to the private sector are given by:

$$\begin{aligned} 0 = 1 - \varepsilon_t^{bs} + \varepsilon_t^{bs}\frac{R_t^b}{r_t^{bs}} - \left(\kappa_{bs}\left(\frac{r_t^{bi}}{r_{t-1}^{bs}} - 1\right) + \frac{1}{\psi_{bs}}\left\{1 - \exp\left[-\psi_{bi}\left(\frac{r_t^{bs}}{r_{t-1}^{bs}} - 1\right)\right]\right\}\right)\frac{r_t^{bs}}{r_{t-1}^{bs}} \\ + \beta_P \mathrm{E}_t\left\{\left(\kappa_{bs}\left(\frac{r_{t+1}^{bs}}{r_t^{bs}} - 1\right) + \frac{1}{\psi_{bs}}\left\{1 - \exp\left[-\psi_{bs}\left(\frac{r_{t+1}^{bs}}{r_t^{bs}} - 1\right)\right]\right\}\right)\frac{\lambda_{t+1}^P}{\lambda_t^P}\left(\frac{r_{t+1}^{bs}}{r_t^{bs}}\right)^2\frac{b_{t+1}^s}{b_t^s}\right\}, \end{aligned} \tag{5}$$

for $s = \{E, H\}$. This resembles a hybrid new Keynesian Phillips curve for the interest rates on loans, where the marginal cost term is the interest rate charged on loans by the management branch. Current bank lending rates depend on (i) their past values, which induce endogenous inertia and (ii) their expected values, as it is worth changing interest rates only if the economic outlook that demands a costly change is expected to last. Furthermore, as a result of the altered Linex adjustment costs, (5) implies that the autoregressive dynamics of BLRs will exhibit higher downward than upward rigidity, in line with the empirical evidence found in Section 2.1.

3.2.2. *The retail deposit and management branches.* The deposit branch collects deposits $d_t^P(j)$ from households at rates $r_t^d(j)$ and lends quantity $D_t(j)$ to the management branch at internal rate $R_t^d(j)$. The balance sheet identity is then $d_t^P(j) = D_t(j)$. We assume that each deposit retail unit faces quadratic adjustment costs for changing the rates it charges on deposits over time, $\mathcal{A}_d\left(\frac{r_t^d(j)}{r_{t-1}^d(j)}\right) = \frac{\kappa_d}{2}\left(\frac{r_t^d(j)}{r_{t-1}^d(j)} - 1\right)^2$, parameterized by κ_d and proportional to the aggregate interest paid on deposits ($r_t^d d_t$). The deposit retail branch's problem, which also operates under a monopolistic competition regime, is to choose the retail deposit rate, applying a markdown to the policy rate to solve:

$$\max_{\{r_t^d(j)\}} \mathrm{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[R_t^d(j)D_t(j) - r_t^d(j)d_t^P(j) - \mathcal{A}_d\left(\frac{r_t^d(j)}{r_{t-1}^d(j)}\right) r_t^d d_t\right], \tag{6}$$

subject to the Dixit-Stiglitz deposit demand curve

$$d_t^P(j) = \left(\frac{r_t^d(j)}{r_t^d}\right)^{-\varepsilon_t^d} d_t. \tag{7}$$

where d_t is the aggregate deposits in the economy and $r_t^d = [\int_o^1 r_t^d(j)^{1-\varepsilon_t^d} dj]^{\frac{1}{1-\varepsilon_t^d}}$ is the deposit rate index, with ε_t^d being the stochastic elasticity of demand for deposits.

The management branch is perfectly competitive. It combines bank capital $K_t^b(j)$ with retail deposits $D_t(j)$ on the liability side and provides wholesale funds $B_t(j)$ to the retail loan branch, with $B_t(j) = b_t^H(j) + b_t^E(j)$. The management activity entails quadratic adjustment costs $\mathcal{A}_{Kb}\left(\frac{K_t^b(j)}{B_t(j)}\right) = \frac{\kappa_{Kb}}{2}\left(\frac{K_t^b(j)}{B_t(j)} - \nu^b\right)^2$, whenever the capital-asset ratio deviates from a required level of ν^b. This exogenous capital requirement is fixed by the regulator. Bank capital is accumulated out of retained earnings:

$$\pi_t K_t^b(j) = (1-\delta^b)\frac{K_{t-1}^b(j)}{\varepsilon_t^{Kb}} + \mathcal{P}_{t-1}^b(j) \tag{8}$$

where $\mathcal{P}_t^b(j)$ is the overall profits of banking group j, δ^b measures resources used in managing bank capital and ε_t^{Kb} is a stochastic shock affecting banks' capital.

After some algebra (i.e., using the balance sheet constraint $B_t(j) = D_t(j) + K_t^b(j)$ twice), the problem for the wholesale branch can be reduced to:

$$\max_{\{B_t(j),D_t(j)\}} \mathrm{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[R_t^b(j)B_t(j) - R_t^d(j)D_t(j) - \mathcal{A}_{Kb}\left(\frac{K_t^b(j)}{B_t(j)}\right)K_t^b(j)\right]. \tag{9}$$

The first-order condition yields a relation linking the spread between wholesale rates on loans and on deposits to the capital-asset ratio or, equivalently, to the inverse of the leverage ratio, $K_t^b(j)/B_t(j)$, such that

$$R_t^b(j) - R_t^d(j) = -\kappa_{Kb}\left(\frac{K_t^b(j)}{B_t(j)} - \nu^b\right)\left(\frac{K_t^b(j)}{B_t(j)}\right)^2 \tag{10}$$

To close the model, it is assumed that banks have access to unlimited funding from a lending facility at the central bank at the policy rate, r_t. Thus, by arbitrage, $R_t^d(j) = r_t$, $\forall j$.

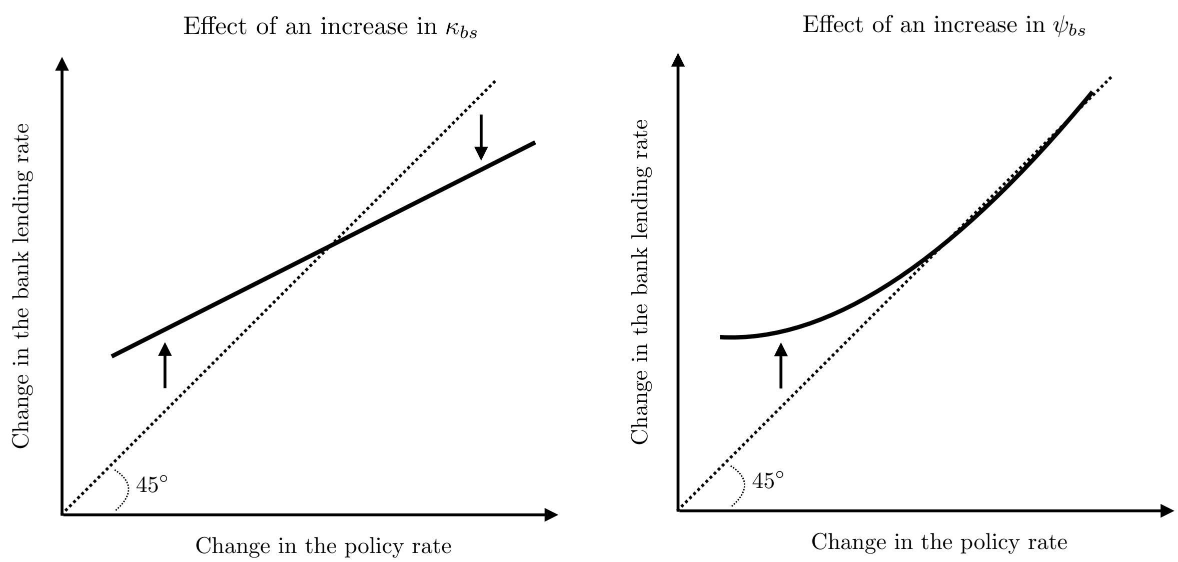
Finally, the overall profits of banking group j are the sum of earnings from the management branch and the two retail branches. After deleting intragroup transactions, overall profits are given by:

$$\begin{aligned}\mathcal{P}_t^b(j) &= r_t^{bH}(j)b_t^H(j) + r_t^{bE}(j)b_t^E(j) - r_t^d(j)d_t^P(j) \\ &- \sum_{i=E,H}\left(\mathcal{A}_{bs}\left(\frac{r_t^{bs}(j)}{r_{t-1}^{bs}(j)}\right)r_t^{bs}b_t^s\right) - \mathcal{A}_d\left(\frac{r_t^d(j)}{r_{t-1}^d(j)}\right)r_t^d d_t - \mathcal{A}_{Kb}\left(\frac{K_t^b(j)}{B_t(j)}\right)K_t^b(j)\end{aligned} \tag{11}$$

4. Calibration and model evaluation

To capture the main structural features of the euro area, the calibration follows the estimates of Gerali et al. (2010), with one exception. We choose to set the steady-state loan-to-value ratios associated with impatient households and entrepreneurs to 0.9, to be more in line with empirical evidence (ECB, 2009), actual regulatory caps (Alam et al., 2019) and the usual calibration of DSGE models (Iacoviello and Neri, 2010; Iacoviello, 2015).[10]

FIGURE 5. The effect of κ_{bs} and ψ_{bs} on the policy and bank lending rates nexus



Next, particular attention is paid to the calibration of the parameters associated with the adjustment cost function. As illustrated by Figure 5, the parameters κ_{bE} and κ_{bH} govern the degree of rigidity of bank lending rates, while the parameters ψ_{bE} and ψ_{bH} determine their degree of asymmetry. These four key parameters are chosen to match the observed volatility and skewness of the year-on-year change in bank lending rates, reported in Table 1 of Section 2. A grid search method is applied to this end. For any pair (κ_{bs}, ψ_{bs}), the model is solved by second-order perturbation methods to capture the nonlinearities embedded in the model, by using Dynare (Adjemian et al., 2021). However, second or higher order approximations can generate unstable steady states and undesirable explosive dynamics due to the accumulation of nonlinear terms higher than the order of approximation. To ensure stationarity in the simulations, we apply the "pruning" method suggested by Kim et al. (2008), which consists in rewriting higher-order terms by relating them to lower-order terms. This approach (i) offers an accuracy as good if not better than the unpruned state-space system, (ii) provides efficient

[10] When considering the same LTV ratios as in Gerali et al. (2010), we can match the second and third empirical moments with the pairs $(\kappa_{bE}, \psi_{bE}) = (4.7, 95)$ and $(\kappa_{bH}, \psi_{bH}) = (4.7, 105)$. This change does not alter our results and key messages. In particular, we obtain relative differences in the initial responses of BLRs to positive and negative shocks that are very close to those obtained with the original calibration.

computation time, and (iii) is well suited when simulations are required to calculate higher-order unconditional moments such as skewness or kurtosis (Andreasen et al., 2018 and Lombardo and Uhlig, 2018). The second and third moments of the year-on-year change in bank lending rates are generated on the basis of 1000 samples of 40 periods, to be consistent with the empirical counterpart.[11] As the effects of κ_{bs} and ψ_{bs} on the skewness of the changes in bank lending rates are not independent, several pairs (κ_{bs}, ψ_{bs}) allow us to reproduce the observed skewness. Nevertheless, many of them can be eliminated, notably those implying high values of κ_{bs}. Indeed, they are not suitable as they create too much distortion, such that (i) the relationship between BLRs and the policy rate becomes horizontal, (ii) the degree of rigidity interferes with the effect of the asymmetric parameter and (iii) rigidity that is too high implies a pass-through that is too low compared to what is found in the data. A detailed illustration of these points is provided in Figure G1 of the Appendix G. Finally, the following pair are selected: $(\kappa_{bE}, \psi_{bE}) = (3.7, 95)$ and $(\kappa_{bH}, \psi_{bH}) = (3.6, 105)$.[12] The values of all model parameters are reported in Table G1 of Appendix G.

TABLE 2. Skewness and variance of year-on-year bank lending rates in the data and models

	Data(1)	Asymmetric model	Symmetric model	Gerali *et al.* model
Skewness of the change in the business rate	0.45	0.45	–0.07	–0.10
Skewness of the change in the mortgage rate	0.56 - 0.64	0.50	–0.09	–0.10
Variance of the change in the business rate	0.45	0.35	0.33	0.32
Variance of the change in the mortgage rate	0.47 - 0.68	0.39	0.35	0.31

(1) For mortgage rates, the range refers to data for France and Germany.

With this calibration, the model can replicate the two empirical facts previously emphasized concerning the skewness of the changes in the BLRs and the asymmetry of the policy rate pass-through. First, Table 2 reports the observed moments ("data") and the simulated moments for three models: (i) our benchmark model with asymmetric adjustment costs (denominated "asymmetric"), (ii) our benchmark model with only quadratic adjustment costs, i.e., $\psi_{bE} = \psi_{bH} = 0$ (denominated "symmetric"), and (iii) the original Gerali et al. (2010) model and calibration. The asymmetric model reproduces both the variance and the skewness of BLRs observed in the data quite well, especially for the mortgage rate. In comparison, the symmetric and Gerali et al. (2010) versions generate weaker variances and, more importantly, negative skewness. The parameters governing the adjustment cost function of the mortgage rate could be increased further to fit the empirical moments even more closely, but a

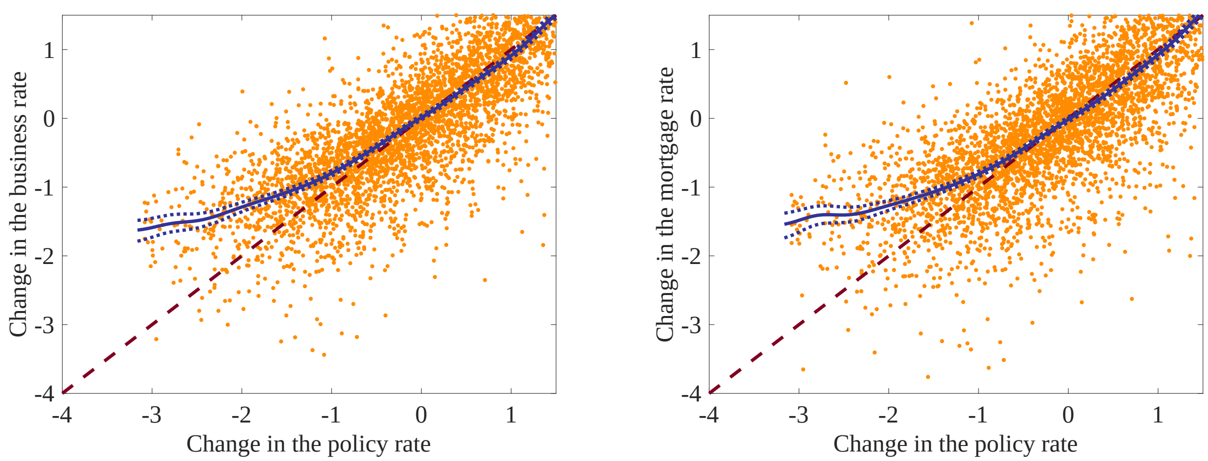
[11]To have different starting points, we simulate as a presample an additional 460 periods that are not included for the computation of the moments.

[12]Note that our calibration of the degree of asymmetry ψ_{bs} is considerably lower than the degrees chosen by Kim and Ruge-Murcia (2009) and Abbritti and Fahr (2013) to calibrate the downward rigidity of wages, namely, 3844 and 24100, respectively.

conservative choice is preferred, as it is sufficient to reproduce the empirical shape of the mortgage–Eonia rates pass-through (see below). Hence, we ensure that the macroeconomic effects of such an asymmetry are not exaggerated thereafter.

Second, our asymmetric model also matches well with the empirical BLR–Eonia nexus. Figure 6 reports the relationship between year-on-year changes in BLRs (r_t^{bE} and r_t^{bH}) and in the policy rate (r_t), based on 4000 simulations of the model (all structural shocks included).[13] The solid blue line represents the nonparametric regression, and the thick dashed lines delineate the 90% confidence interval obtained by standard bootstrap techniques. We remark that this simulated relationship is very close to the empirical one shown in Figure 2. Thus, as our structural model can reproduce the empirical facts under review, it is well suited to evaluating the macroeconomic consequences of downward lending rate rigidity.

FIGURE 6. Simulated changes in the policy rate and bank lending rates (percent)



Note: The scatter plot is based on 4000 simulations of the asymmetric model (all structural shocks included). The solid blue line represents the nonparametric regression, and the thick dashed lines delineate the 90% confidence interval obtained by standard bootstrap techniques.

5. ASSESSING THE MACROECONOMIC EFFECTS OF DOWNWARD INTEREST RATE RIGIDITY

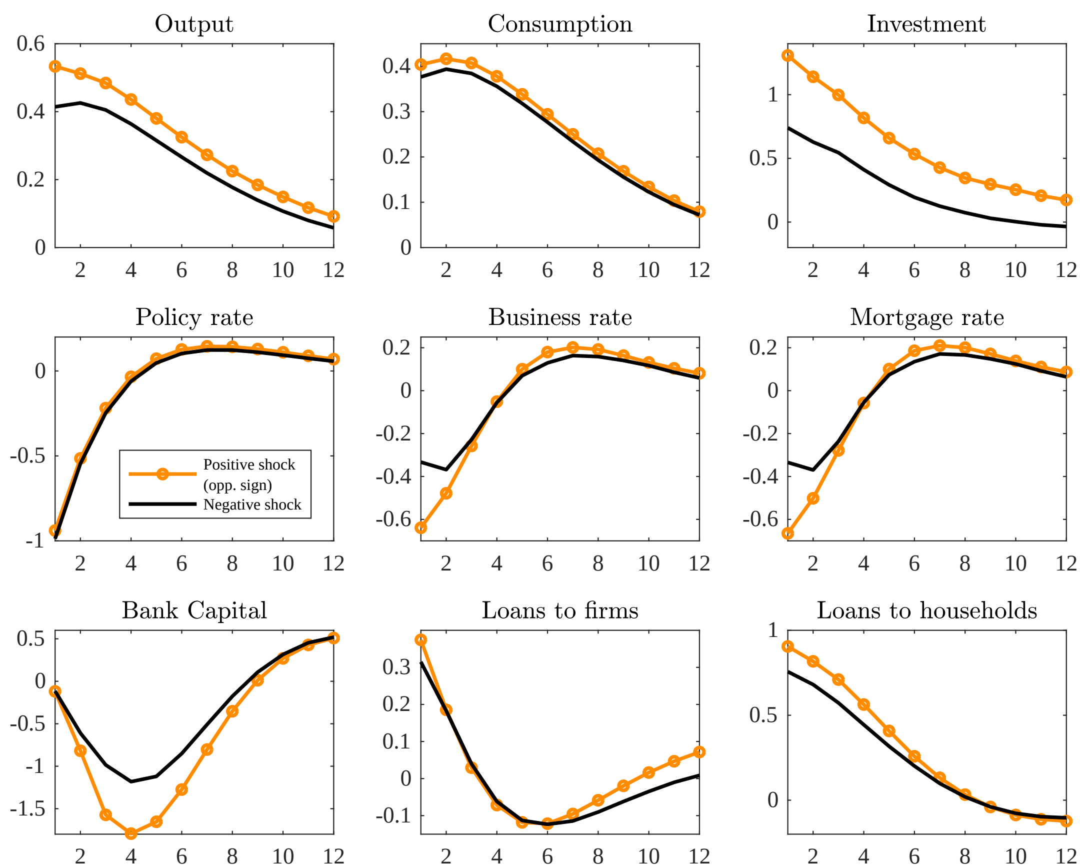
In this section, we first show that downward interest rate rigidity involves significant macroeconomic losses. This implies that monetary policy, as a key determinant of BLRs, is less efficient in pushing the economy up than in pulling it down. From this perspective, downward BLR rigidity can contribute to explain why loosening monetary policy in the case of downturn is like "pushing on a string". We then consider how monetary policy could deal with this asymmetry.

[13] The policy rate in Figure 6 moves (i) in response to changes in economic forces (systematic part of the monetary policy rule) and/or (ii) following unanticipated/atypical decisions by the central bank (discretionary part).

5.1. **Asymmetric responses to different shocks.** To study the macroeconomic consequences of downward interest rate rigidity, we compare the dynamic responses of key variables to positive and negative shocks (monetary policy, technology and bank capital) of similar amplitude.

Figure 7 shows the impulse responses to positive and negative monetary policy shocks of equal size (100 basis points away from the steady state, in annual terms). The circled orange line represents the case of monetary contraction, i.e., a rise in the policy rate, while the black line shows the case of monetary expansion, i.e., a fall in the policy rate. Note that the responses to the positive shock are displayed in opposite sign to facilitate the comparison with the accommodative monetary policy shock. The x-axis indicates the time horizon in quarters. The y-axis denotes (i) the absolute deviations from the steady state (expressed in percentage points) for the interest rates or (ii) the percentage deviation from the steady state for all other variables.

FIGURE 7. Monetary policy shock



Note: Horizon in quarters. The simulation shows the dynamic responses to positive and negative monetary policy shocks of equal size (100 basis points away from the steady state, in annual terms). The positive shock is shown in the opposite sign to facilitate comparison.

We observe that the asymmetric properties of the nonlinear model are consistent with the empirical facts presented in Section 2. Indeed, while the transmission channels are the same, irrespective of the sign of the initial monetary policy shock, the amplitude of the responses is clearly different. On the one hand, we can see that an increase in the policy rate implies a rise of the wholesale deposit rate (R^d). As a consequence, banks manage their balance sheets by raising their wholesale credit rate R^b (see equation 10). Banks' retail loan branches pass this increase on in BLRs to households and entrepreneurs, albeit not completely because of the presence of some quadratic adjustment costs.[14] Rising interest rates discourage loans, consumption and investment expenditure; hence, output declines. This depressive effect is reinforced by a decline in housing and capital prices: the inherent drop in collateral makes loans to impatient households and entrepreneurs decrease even more.

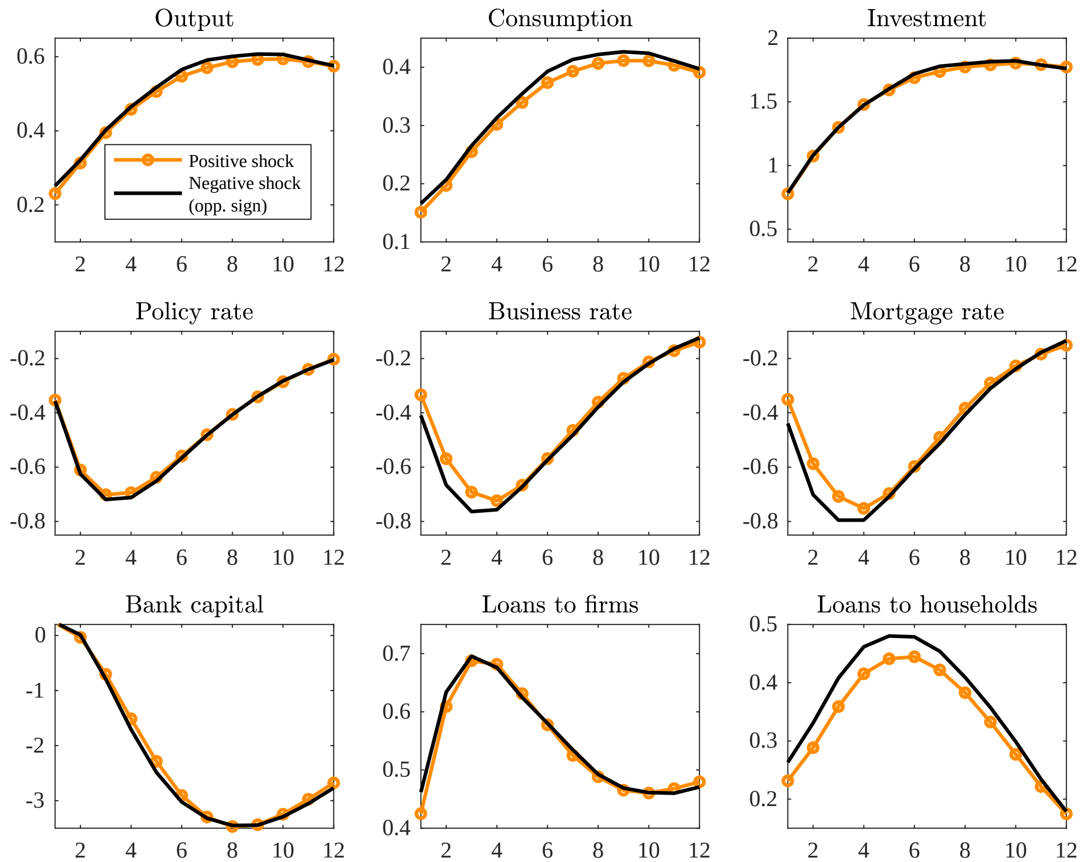
On the other hand, when monetary policy is expansionary, the increase in output and its components is weaker than the responses of these variables to the contractionary shock. The reason is that downward adjustment costs drastically reduce the responses of the business and household lending rates: the initial decreases in these rates are half as large as in the case of the positive shock. This implies that consumption and investment initially increase by 7% and 43% less, respectively, than they decrease in the case of a positive shock. Hence, the output increase is approximately 22% lower than the output decline that is obtained in the case of a positive shock of similar amplitude. It represents a loss of approximately 14 billion euros of 2019 GDP when the shock occurs and a cumulated GDP difference of approximately 88 billion euros of 2019 GDP over a three-year horizon.

These macroeconomic effects also prevail for other shocks. Figure 8 shows the effects of positive and negative technology shocks. As usual, a positive technology shock triggers an increase in output but a decrease in inflation, which makes the central bank cut its policy rate. This drop in the interest rate is slightly passed on through bank lending rates, whereas bank lending rates are promptly raised in the wake of monetary policy tightening due to a negative technology shock. As a consequence, for a shock of similar amplitude, output decreases by approximately 10% more in bad times over the three-year horizon than it increases in good times. This represents a loss of approximately 2.5 billion euros of 2019 GDP at the impact, and a cumulated GDP difference of about 17 billion euros of 2019 GDP over a three-year horizon.

Another example is provided by Figure 9 which shows the effects of positive and negative bank capital shocks. By definition (see equation 8), a "positive" bank capital shock means an exogenous decrease in bank capital. This shock requires banks to scale their loan portfolios down to meet their regulatory capital-to-asset requirements and to increase their net interest margin to accumulate earning profits, which is the only way to rebuild capital. These adjustments are achieved by an increase

[14] Note that the increase in BLRs compensates for the decline in credit volume and makes the profits of banks rise in the end (see equation 11). As a consequence, banks accumulate more capital (see equation 8).

FIGURE 8. Technology shock



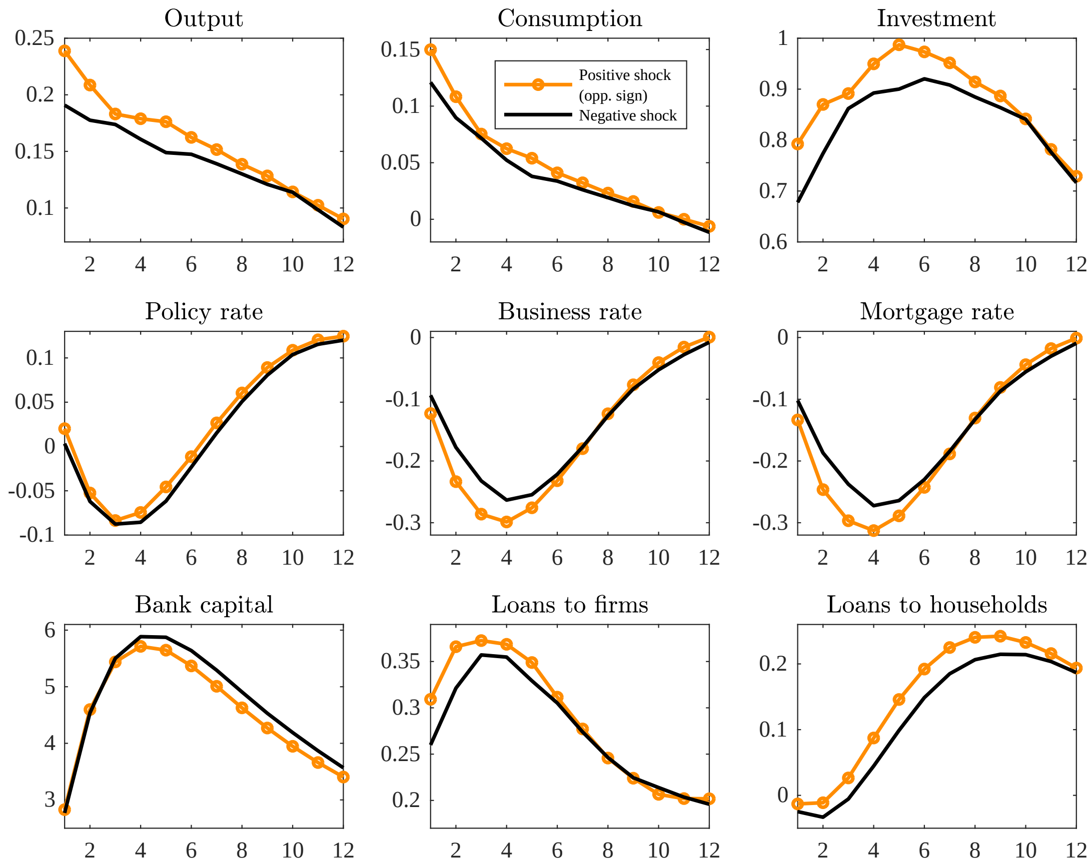
Note: Horizon in quarters. The simulations show the dynamic responses to positive and negative technology shocks of equal size (one standard deviation). The negative shock is shown in opposite sign to facilitate comparison.

in lending rates. As a result, loans are actually reduced, as is output, while bank capital gradually recovers.[15] In contrast, in the case of an exogenous increase in bank capital, i.e., a "negative" shock, the regulatory constraint is relaxed. Hence, banks reduce their excess capital, but by moderately cutting their rates because of high(er) adjustment costs. As a consequence, an exogenous decrease in bank capital has more dramatic real effects than an exogenous increase of similar amplitude; the change in output is about one-fifth higher, at the impact, compared with the symmetric case.[16] This represents a loss of about 6 billion euros of 2019 GDP when the shock occurs and a cumulated GDP difference of approximately 22 billion euros of 2019 GDP over a three-year horizon. This result suggests that

[15]Not only does the deposit rate increase less than lending rates, but deposits also decrease in the wake of this recessive shock.

[16]Since monetary policy and bank capital shocks have a direct impact on bank lending rates, through the dynamics of the policy rate for the former and the adjustment of bank balance sheets for the latter, they imply larger real deviations with respect to the symmetric case than the technology shock.

FIGURE 9. Bank capital shock



Note: Horizon in quarters. The simulations show the dynamic responses to positive and negative bank capital shocks of equal size (one standard deviation). The positive shock is shown in opposite sign to facilitate comparison.

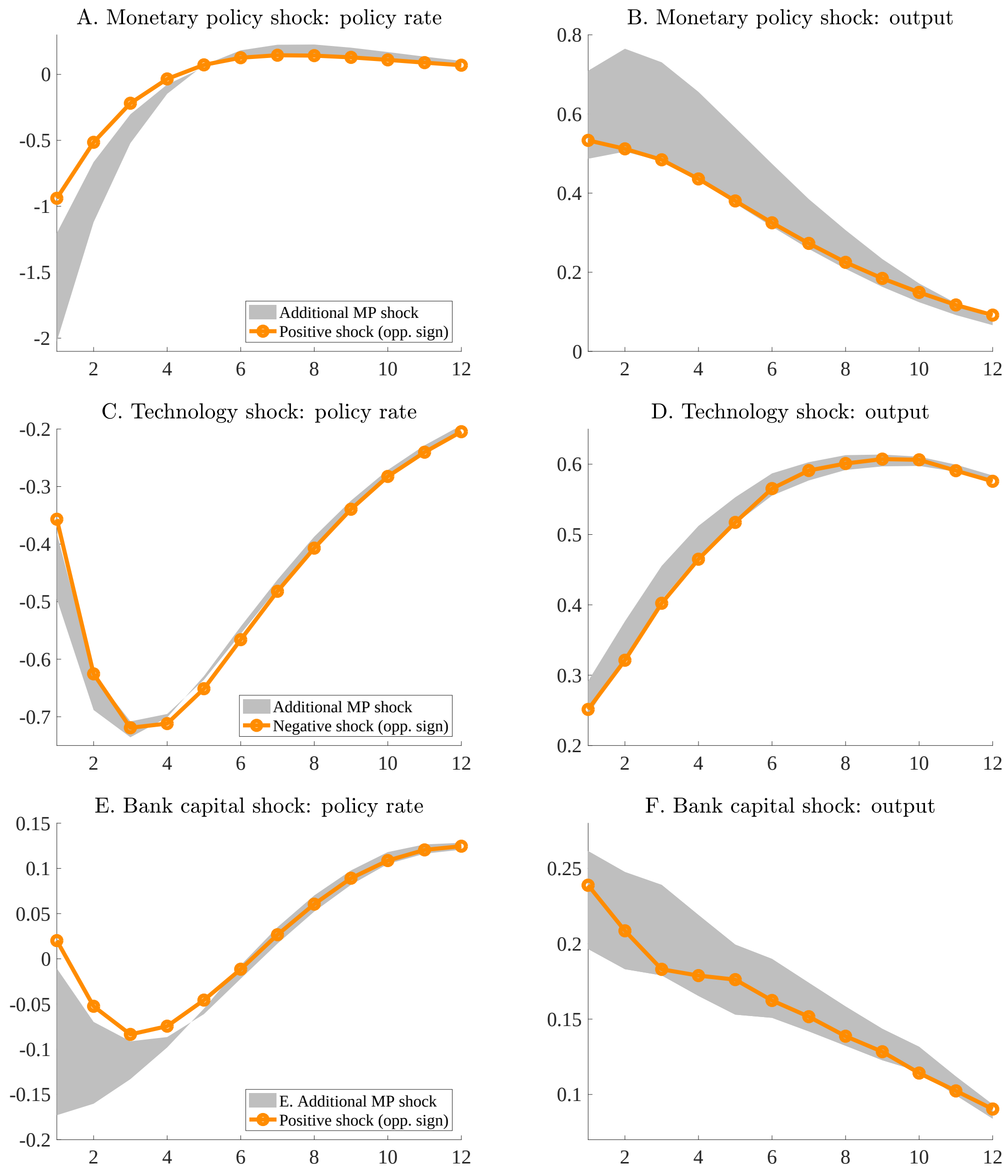
a "cleanup afterwards" strategy intended to dampen a banking crisis may have a rather limited impact, except if the central bank agrees to lower its policy rates very sharply and if there is room for manoeuvre to do so.

To summarize, while these figures should be taken with caution due to the usual statistical uncertainty surrounding structural parameter values and shock processes, downward interest rate rigidity has notable real macroeconomic effects.

5.2. **Dealing with asymmetry: the role of monetary policy.** We now examine the effort that the central bank could make to compensate for the downward rigidity of BLRs. For each shock, we search the amount of "additional (negative) monetary policy shocks" necessary to reach a GDP response similar, in absolute value, to that obtained when the policy rate increases.[17] Figure 10 reports the results of this exercice for monetary policy, technology and bank capital shocks.

[17] Technically, we vary the size of monetary policy shocks (their innovations) which act negatively in the monetary policy rule, simultaneously with the structural shock hitting the economy.

FIGURE 10. Negative monetary policy shocks to reach a symmetric GDP response



Note: Horizon in quarters. All shocks are of opposite signs such that the output response corresponds to the baseline case where the policy rate increases (orange line). The gray area corresponds to different sizes of additional negative monetary policy shocks.

The gray area reported on Panel A indicates that a central bank would have to decrease its policy rate by 20% to 100% more to obtain an effect on GDP equal (in absolute value) to that of a positive monetary policy shock (Panel B) over a three-year period. When we look at the technology shock, we observe that the policy rate should be cut by 3 to 35% more (Panel C) to ensure an increase in GDP that would be equivalent to its decrease (Panel D). Finally, we consider the case of a bank capital shock. A positive shock, i.e., a decrease in bank capital, is the benchmark to reach, as it implies an increase in BLRs and an inherent decrease in output. The gray area in Panel E of Figure 10 shows that, one quarter after the shock, the interest rate cut should be at least 1.3 and up to 3 times higher than the interest rate hike prevailing in the symmetric context, to boost output equivalently.

Hence, this investigation implies that neglecting downward interest rate rigidity within a macroeconomic model or in the general appraisal of the interest rate transmission mechanism may yield misguided monetary policy decisions.

6. Unconventional monetary policy transmission to bank lending rates

So far, we have shown that downward interest rate rigidity impedes the effectiveness of monetary policy in normal times, i.e., when the ECB's key policy rate is implemented via its weekly main refinancing operations (MROs), as soon as it has not reached its lower bound. However, in July 2012, the ECB decided to lower rates by 25 basis points, bringing the deposit facility rate (one of its standing facilities), to 0 percent, which was then left unchanged for almost two years, until it dipped into negative territory in June 2014. The negative deposit facility rate also applies to average reserve holdings in excess of the minimum reserve requirements and to other deposits held with the Eurosystem. At the same time, several unconventional measures, such as forward guidance, liquidity injections and large-scale asset purchases, have also been implemented, making the Eonia rate poorly illustrative of monetary policy (see Hartmann and Smets, 2018, for a review). How these unusual measures influenced bank lending rates is an important issue.

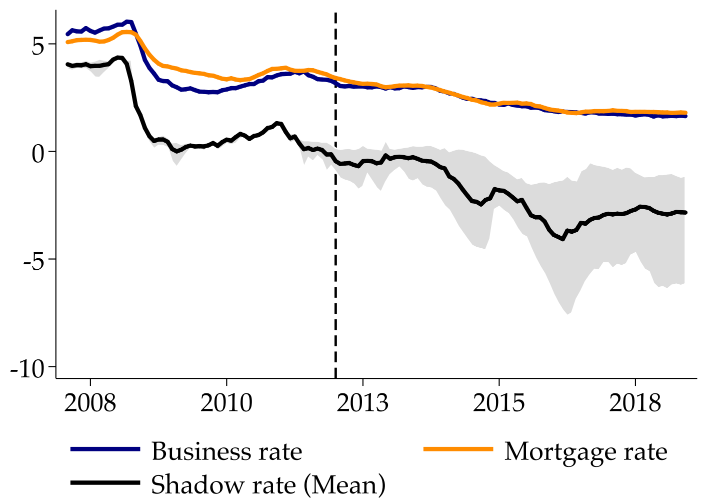
The literature has attempted to answer this question using microeconomic data at the bank level with mixed conclusions (see Rostagno et al., 2019, for a review). At the macroeconomic level, a useful way to summarize the unconventional policy actions is to refer to the so-called shadow rate. The shadow rate is the shortest maturity rate, extracted from a term structure model, that would generate the observed yield curve had the effective lower bound not been binding. Specifically, exploiting the entire yield curve allows us to account for the influence of direct and/or indirect market interventions on intermediate and longer maturity rates.[18] The shadow rate coincides with the market rate (Eonia or the fed funds rate, for instance) in normal times and is free to go into negative territory when the market rate is stuck at its lower bound. Wu and Xia (2016), Sims and Wu (2019) and Mouabbi and Sahuc (2019) incorporate shadow rates into vector autoregressive or DSGE models to analyze the effects of unconventional monetary policies.

To capture the uncertainty surrounding its measurement, we consider a set of four shadow rates proposed by Krippner (2015), Wu and Xia (2016), Kortela (2016) and Lemke and Vladu (2017). The gray area in Figure 11 reports the range of the corresponding shadow rates, while the black line is the mean value of this set of shadow rates. While the large and persistent decline in the shadow rate

[18]Notice that not all unconventional measures do translate into a change in the shadow rate, such as the TLTROs which provide direct financing to credit institutions. Consequently, the shadow rate may underestimate the accommodative stance of monetary policy.

can be interpreted as evidence of the effectiveness of monetary policy on the yield curve, this figure also emphasizes that there is a disconnection between the shadow rate and bank rates in a negative rate environment. Indeed, BLRs did not decrease as much as the shadow rates did, suggesting an ineffective pass-through of unconventional monetary policies to lending rates. This breakdown in the pass-through is even more obvious in Figure 12, which shows that BLRs reacted slightly downward as the shadow rate was decreasing (orange points), but with a constant amplitude (approximately 50 bp), irrespective of the size of shadow rate changes.[19]

FIGURE 11. Bank lending rates, shadow rates and negative interest rate environment (percent)



Note: The gray area represents the interval from the minimum to the maximum value of the shadow rate. The vertical dashed line refers to July 2012, when the deposit facility rate was set at 0%.

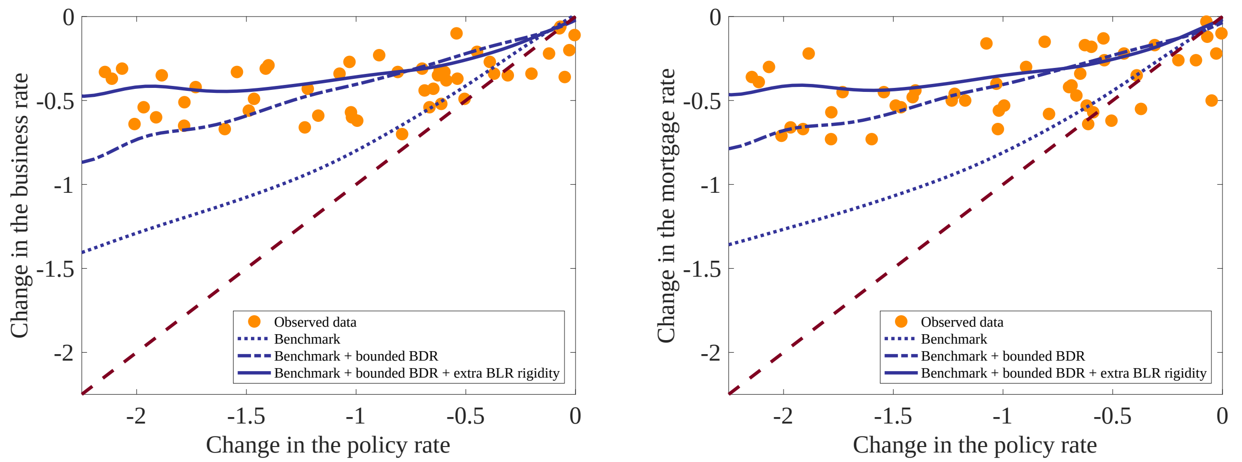
This disruption of the pass-through as the shadow rate decreases may have at least two explanations. First, there may be a positive lower bound on BLRs ("Bounded BLR" hypothesis) due to (i) incompressible agency and fixed costs that banks have to manage in their intermediation activities and (ii) positive premiums they charge on loans. Second, banks may have been reluctant to decrease their BLRs further for profitability reasons, related to the existence of a lower bound on bank deposit rates ("Bounded BDR" hypothesis). Indeed, bank deposit rates have been highly rigid since 2012, and they tend to be bounded close to zero, especially for household deposits (see Appendix B).[20] As a consequence, unconventional monetary policies in general and negative policy rates in particular did not translate to lower and negative rates on retail deposits (Heider et al., 2019). Therefore, cutting lending

[19]Note that we observe a breakdown in the pass-through but not adverse effects such as those found, e.g., by Eggertsson et al. (2019) and Brunnermeier and Koby (2018).

[20]The first row of Figure B2 in Appendix B shows that, as long as the market rate had not reach the ELB, deposit rates reacted to changes in the Eonia rate, albeit less than proportionally (but with no evidence of asymmetry). The second row of Figure B2 indicates that the pass-through has been considerably altered after 2012: the relationship between the shadow rate and the bank deposit rates has broken down.

rates while deposit rates remain constant would imply a decrease in banks' net interest margin. In practice, as in our model, this would lower banks' retained earnings and prevent banks from meeting the regulatory capital-to-asset ratio. Instead, it may be preferable for banks to moderate the decrease in their lending rates.[21]

FIGURE 12. Observed and simulated scatter plots of the changes in the policy and bank lending rates over 2012-2018 (percent)



Note: The orange points ("observed data") represent the pairs of changes in the shadow rate and bank lending rates. The blue lines report the nonparametric regressions of the scatter plots based on 4000 simulations for three model specifications: (i) "benchmark" corresponds to the asymmetric model ($\kappa_{bE} = 3.7$, $\psi_{bE} = 95$, $\kappa_{bH} = 3.6$, $\psi_{bH} = 105$, and $\kappa_d = 3.5$), (ii) "benchmark + bounded BDR" corresponds to the benchmark specification with a huge adjustment cost on the bank deposit rate ($\kappa_{bE} = 3.7$, $\psi_{bE} = 95$, $\kappa_{bH} = 3.6$, $\psi_{bH} = 105$ and $\kappa_d = 400$), and (iii) "benchmark + bounded BDR + extra BLR rigidity" corresponds to the specification (ii) with an extra rigidity and asymmetry of bank lending rates ($\kappa_{bE} = 10$, $\psi_{bE} = 250$, $\kappa_{bH} = 10$, $\psi_{bH} = 250$ and $\kappa_d = 400$).

To disentangle the two hypothesis ("bounded BLR" *vs.* "bounded DBR"), we perform a new set of simulations, the results of which are shown in Figure 12. We first observe that the "benchmark" asymmetric model studied in the previous section poorly matches the pass-through observed over 2012-2018 (scatter points). Adding "bounded BDR" to this benchmark, by largely increasing κ_d (from 3.5 to 400), allows the model to be closer to the observed data. This means that this lower bound on BDR is a major explanation of the dynamics of BLRs. However, an additional increase in the intrinsic rigidity and skewness of BLRs is required to properly reproduce the (disrupted) pass-through of the shadow rate to BLRs. This is illustrated by the configuration called "extra BLR rigidity", obtained by increasing κ_{bE} and κ_{bH} from 3.7 and 3.3 to 10, respectively, as well as by increasing ψ_{bE} and ψ_{bH} from 95 and 105 to 250, respectively.

These results indicate that despite many unconventional measures, retail rates do not seem to adjust downward as the policy rate is at its effective lower bound. This is mainly due to the existence of a lower bound on deposit rates but also to a lower bound on BLRs stemming from frictions that

[21] Amzallag et al. (2019) actually find that banks with greater ratios of overnight deposits to total assets tend to charge higher rates on new fixed rate mortgages in Italy.

are intrinsically related to banks' business model. In Europe, a weaker intermediation margin could hardly be compensated by other sources of profitability because of overcapacity (low cost-efficiency) and insufficiently diversified structure of revenues (weak income-generation capacity). Such a deterioration in profitability may induce a lower bound on lending rates that reduces the effectiveness of monetary policy.

Hence, this asymmetric response of BLRs, which deteriorates the pass-through of monetary policy in periods of ultra-low interest rates, justifies a strong reaction to negative shocks. For example, this supports the large-scale unconventional measures implemented by central banks in 2020 to counteract the economic impact of the Covid-19 pandemic. In particular, by modifying some of the key parameters of its TLTRO-III, the ECB has sought specifically to ensure the transmission of its accommodative policy. Under these new conditions, banks can benefit from more favourable rates according to their credit performance, thus supporting bank lending to firms and households, and ultimately output. By mobilizing other channels, those measures seek to directly target the quantity of loans (real effect) rather than their prices that are bounded, illustrating the "pushing on a string" metaphor.

7. Concluding remarks

This paper shows that downward interest rate rigidity has important macroeconomic consequences and that neglecting it can thus lead to misguided monetary policy decisions. By introducing asymmetric bank lending rate adjustment costs in a macrofinance dynamic stochastic general equilibrium model, we find that the difference in the initial response of GDP to positive and negative shocks of similar amplitude can reach up to 25%. This means that a central bank would have to cut its policy rate much more to obtain a medium-run impact on GDP that would be symmetric to the impact of a shock implying a policy rate increase. We also show that these findings are exacerbated when policy rates are stuck at their effective lower bound. This is due to a lower bound on deposit rates (for profitability purposes) and to a lesser extent to frictions that are intrinsically related to banks' business model, which finally account for the existence of a lower bound on BLRs.

This current work opens room for many extensions. First, as downward interest rate rigidity has significant macroeconomic effects, it is worth explicitly modeling its microfoundations. Subsequent analysis could investigate, for instance, whether asymmetric costs may arise endogenously from the maximization of bank profits. Second, our findings raise the issue of the optimality of monetary policy in the context of downward interest rate rigidity. Does such rigidity call for an asymmetric loss function? Should it imply an optimal asymmetric response to shocks, with a stronger reaction to negative than to positive shocks? Furthermore, as stimulating economic growth with monetary policy is like "pushing on a string", the effort required may be so important that hitting the effective lower bound is more likely, especially in a context of a downward trend in the natural interest rate. This specific point suggests that the microfoundation of downward interest rate rigidity could rely on adjustment costs that would be endogenous to the level of interest rates, i.e., following an asymmetric process that would be not only size-driven but also level-driven. Third, and as a consequence, it is important to determine how to deal with the deterioration of monetary policy pass-through that we have found when the effective lower bound constraint of the policy rate is binding. In particular, banks may be reluctant to decrease their lending rates for profitability reasons and because the potential drop in their net worth may compromise their ability to meet capital requirements. Loosening capital requirements in times of economic downturn, like in March 2020 in the context of the Covid pandemic, may be viewed as a solution to restore the transmission of monetary policy. Such potential benefits of macroprudential policy would deserve further investigation (see, e.g., Darracq Pariès et al., 2020).

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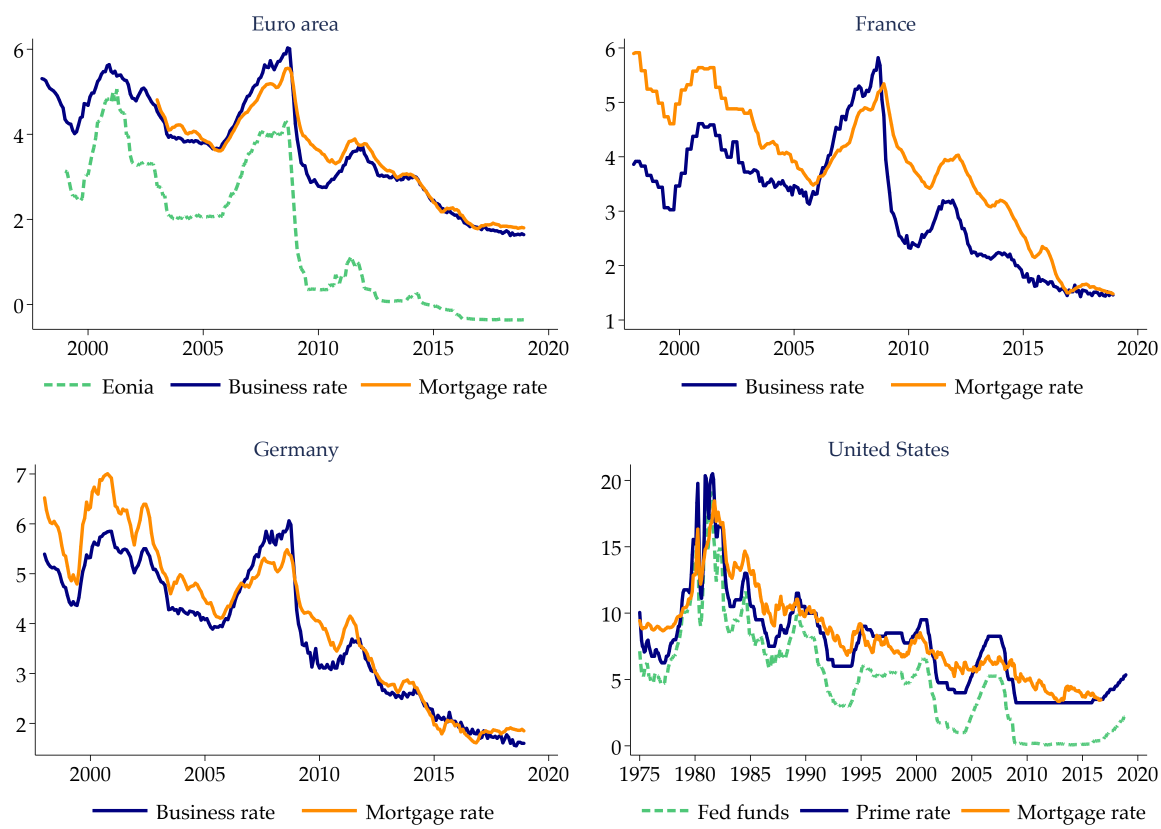
Appendix A. Data sources

Data for the euro area (EA), France and Germany come from the ECB Statistical Data Warehouse in monthly frequency. We use harmonized monthly data from January 2003 onward from the MFI Interest Rate (MIR) statistics on new business coverage. The bank lending rate to nonfinancial companies corresponds to the "cost of borrowing for corporations", and the lending rate to households is the "cost of borrowing for households for house purchase". These data from MIR are back-extrapolated from January 2003 to January 1998 according to the evolution of the retail bank lending rates, which come from the Retail Interest Rate (RIR) database compiled by the ECB until September 2003. This operation was not possible for the euro area mortgage rate, which is not available in the RIR dataset. Deposit rates for the euro area from January 2000 onward come from the MIR database. These rates relate to "non-financial corporations" and to "households and non-profit institutions serving households". These two series are extended back to January 1999 on the common basis of the change in the "overnight deposit", available in the RIR database. Finally, Eonia corresponds to its monthly average value. Data for the United States, namely, the federal funds rate, the prime rate and the mortgage rate charged by banks, come from the Federal Reserve Economic Database (FRED) and cover the period 1975-2018. All these interest rates are represented in Figure A1 and B1.

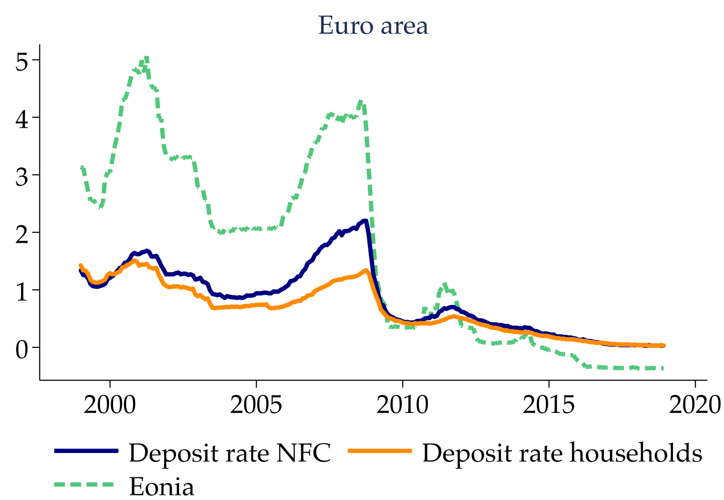
FIGURE A1. Market rates and BLRs in the EA, France, Germany and the United States (percent)



APPENDIX B. SPECIFICS ON BANK DEPOSIT RATES

As the dynamics of bank deposit rates (BDRs) may also influence the transmission of monetary policy through their potential influence on the BLR, for net interest margin purposes, and through their impact on household saving and consumption behavior, their properties are worth examining. Figure B1 below represents the BDR for nonfinancial corporations and for households since January 1999. First, we observe a very smooth evolution of the BDR, suggesting that the rates are not truly responsive to Eonia.

FIGURE B1. Bank deposit rates for nonfinancial corporations (NFCs) and households (percent)



Second, autocorrelation functions (available upon request) indicate that BDRs are more rigid than BLRs, with no evidence of differences depending on the sign of the changes, while an upward rigidity might have been expected. Finally, Table B1 shows that the hypothesis of asymmetric evolution of deposit rates is rejected. Their skewness is not significantly different from zero. As a consequence, there is no asymmetric reaction of the deposit rates to Eonia: the skewness of Δ deposit rate–Δ Eonia is not significantly different from zero.

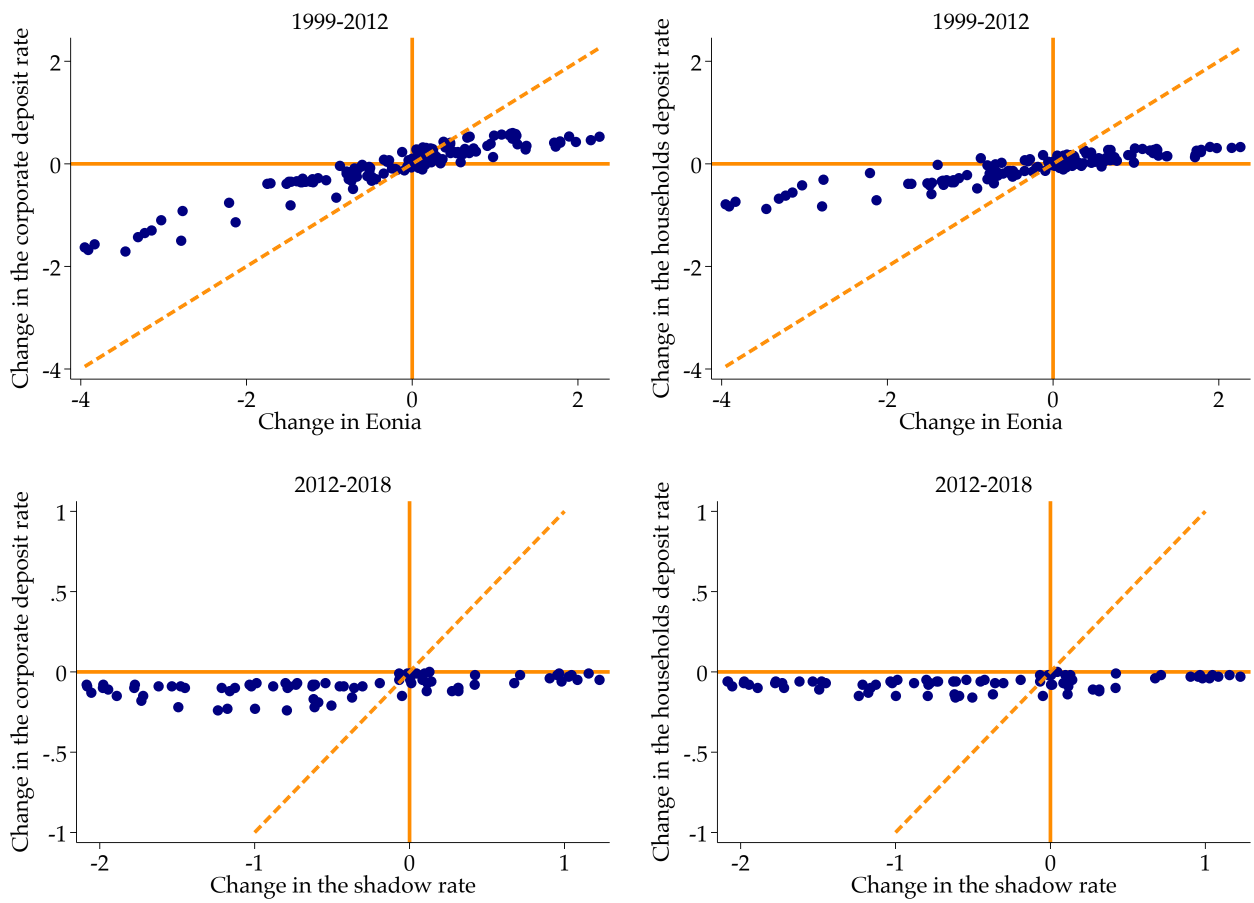
TABLE B1. Skewness of year-on-year changes in deposit rates

	Δ deposit rate	Δ deposit rate–Δ Eonia
Nonfinancial corporations	0.16 [0.49]	-0.24 [0.31]
Households	-0.13 [0.58]	-0.23 [0.33]

Note: P-values for the null of no skewness are in square brackets (1999-2007).

Finally, while there is no evidence of asymmetry in the changes of deposit rates before 2012, Figure B2 indicates that the pass-through of monetary policy to deposit rates has deteriorated after 2012.

FIGURE B2. Scatter plots of the changes in the market and bank deposit rates (percent)



Appendix C. Additional empirical evidence

Table C1. Skewness of year-on-year changes in the market and bank lending rates (post global financial crisis)

Interest rate	Euro area	France	Germany	United States
Market rate	-1.17	-	-	-1.88
	[0.00]	-	-	[0.00]
Business	-1.10	-1.12	-0.97	-1.81
	[0.00]	[0.00]	[0.00]	[0.00]
Mortgage	-0.74	-0.49	-0.18	-0.06
	[0.02]	[0.10]	[0.53]	[0.77]

Note: The market rate corresponds to Eonia for the euro area and to the effective federal funds rate for the United States. The skewness is computed over 2007-2012 for the euro area, France and Germany, and over 2007-2018 for the United States. P-values for the null hypothesis of no skewness are in square brackets.

Table C2. Threshold autoregressive model (SETAR) for the lending rate to nonfinancial corporations

	France	Germany	United States
$\Delta BLR_{t-1} \leqslant \varsigma$	0.299*	0.867*	0.604*
	(0.104)	(0.210)	(0.160)
$\Delta BLR_{t-1} > \varsigma$	-0.003	0.121	0.333
	(0.081)	(0.109)	(0.252)
Threshold ς	0.00	-0.10	0.00
LM Sup$^{(a)}$	7.53 [0.19]	9.42 [0.10]	17.0 [0.00]
LM Exp$^{(a)}$	2.99 [0.06]	3.36 [0.04]	6.77 [0.00]
LM Ave$^{(a)}$	5.92 [0.03]	6.31 [0.02]	12.1 [0.00]

Note: (a) LM Sup, LM Exp and LM Ave refer to the statistics for the null hypothesis of three alternative tests of no threshold effects (Hansen, 1996). Tests are based on 5000 draws. Corresponding p-values are in square brackets. Tests and estimates are run for the period 1998-2012 for France and Germany, and for the period 1975-2018 for the United States. Heteroskedasticity-consistent standard errors of estimates are in parentheses.
* designates statistical significance at the 1% level.

To further study the BLR-market rate nexus, Table C3 reports the skewness of the difference between the year-on-year change in bank lending rates and the year-on-year change in Eonia, over 2004-2012. We observe a significantly positive skewness for the euro-area business spread (1.08) and an even higher positive skewness for the euro-area mortgage spread (1.69) over the period 2004-2012. This means that BLRs did not decrease as strongly as policy rates in the wave of the financial crisis. Such a downward rigidity of BLRs is also found for France and Germany over different periods, as well as for the United States over a longer period (1975-2018).

TABLE C3. Skewness of the difference of year-on-year changes in BLRs and year-on-year changes in market rates

	Euro area	France		Germany		United States	
	2004-2012	1999-2012	2004-2012	1999-2012	2004-2012	1975-2007	2008-2018
Business	1.08	0.33	1.04	-0.06	1.52	0.51	1.07
	[0.00]	[0.09]	[0.00]	[0.73]	[0.00]	[0.00]	[0.00]
Mortgage	1.69	1.39	1.62	1.05	1.75	1.09	1.48
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]

Note: The market rate corresponds to Eonia for the euro area, France and Germany and to the effective federal funds rate for the United States. P-values for the null hypothesis of no skewness are in square brackets.

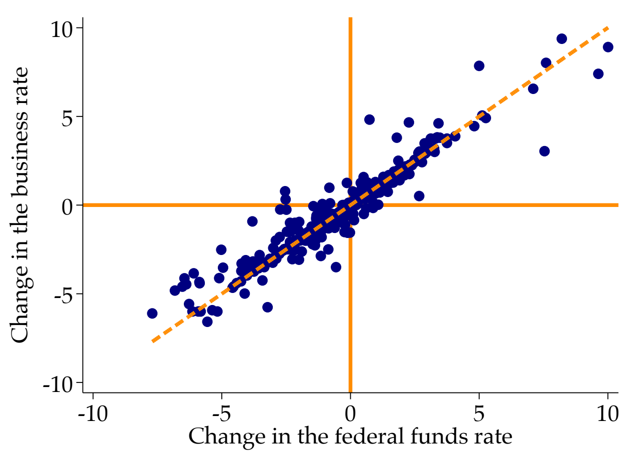
APPENDIX D. ADDITIONAL ELEMENTS ON BANK LENDING RATE STATISTICS IN THE UNITED STATES

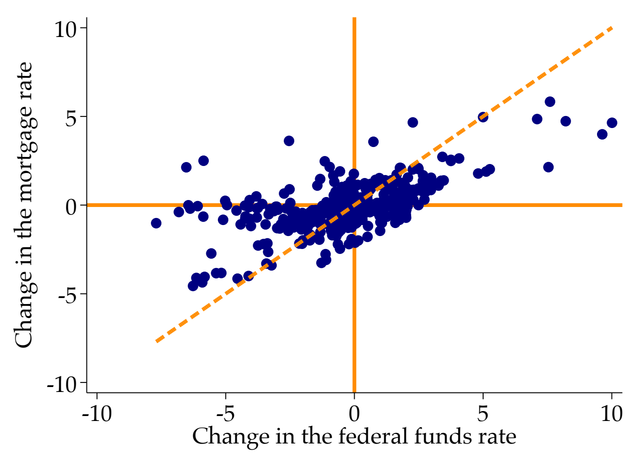
TABLE D1. Skewness of year-on-year changes in US bank lending rates and the fed funds rate

	1975 - 2007		1975 - 2018	
Business rate	0.258	[0.03]	0.258	[0.01]
Mortgage rate	0.351	[0.00]	0.470	[0.00]
Fed funds rate	0.127	[0.29]	0.098	[0.35]
Δ Business rate - Δ fed funds rate	0.510	[0.00]	0.673	[0.00]
Δ Mortgage rate - Δ fed funds rate	1.096	[0.00]	1.120	[0.00]

Note: P-values for the null hypothesis of no skewness are in square brackets.

FIGURE D1. Scatter plots of year-on-year changes in the fed funds rate and bank lending rates in the United States over 1975-2018 (percent)





APPENDIX E. THE REST OF THE MODEL

In this appendix, we expound on the remaining parts of the model.

E.1. **Households.** Households can be patient (P) or impatient (I), which results in a subjective discount factor higher for the former than for the latter, $\beta_P > \beta_I$. The preferences of the ith household are given by:

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta_\zeta^t \left[\left(1 - a^\zeta\right) \varepsilon_t^z \log\left(c_t^\zeta(i) - a^\zeta c_{t-1}^\zeta\right) + \varepsilon_t^h \log h_t^\zeta(i) - \frac{l_t^\zeta(i)^{1+\phi}}{1+\phi} \right], \text{ for } \zeta \in \{P, I\} \tag{E1}$$

where E_t denotes the mathematical expectation operator upon information available at t, $a^\zeta \in (0,1)$ denotes the degree of habit formation, and $\phi > 0$ is the inverse of the Frisch labor supply elasticity. $c_t^\zeta(i)$ denotes individual consumption, c_{t-1}^ζ is lagged aggregate consumption, $h_t^\zeta(i)$ is housing services and l_t^ζ represents hours worked. In addition, ε_t^z and ε_t^h capture exogenous shocks affecting consumption and the demand for housing, respectively.

Patient household i's period budget constraint is given by

$$c_t^P(i) + q_t^h \Delta h_t^P(i) + d_t^P(i) \leq w_t^P l_t^P(i) + (1 - r_{t-1}^d) d_{t-1}^P(i)/\pi_t + \tau_t^P(i) \tag{E2}$$

where q_t^h is the real house price, $d_t^P(i)$ is real deposits in period t, w_t^P is the real wage rate for the labor input of each patient household, $\pi_t \equiv P_t/P_{t-1}$ is gross inflation, and τ_t^P are lump-sum transfers that include labor net union membership fees and firm and bank dividends (of which patient households are the only owners).

Impatient household i's period budget constraint is given by

$$c_t^I(i) + q_t^h \Delta h_t^I(i) + (1 + r_{t-1}^{bH}) b_{t-1}^I/\pi_t \leq w_t^I l_t^I(i) + b_t^I(i) + \tau_t^I(i) \tag{E3}$$

where $b_t^I(i)$ is the amount of new loans, and the other variables are similar to those of the patient households, except the lump-sum transfers $\tau_t^I(i)$ that only include net union fees.

In addition, impatient households face a borrowing constraint that states that the household can borrow up to the expected value of their housing:

$$(1 + r_t^{bH}) b_t^I(i) \leq \varepsilon_t^{mI}\, \mathrm{E}_t \left[q_{t+1}^h h_t^I(i) \pi_{t+1} \right] \tag{E4}$$

where ε_t^{mI} is the stochastic loan-to-value ratio for mortgages.

E.2. **Entrepreneurs.** Entrepreneur i's utility depends only on his own consumption $c_t^E(i)$ and the lagged aggregate consumption:

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta_E^t \log\left(c_t^E(i) - a^E c_{t-1}^E\right) \tag{E5}$$

where a^E measures the degree of consumption habits, similar to households, and the discount factor β_E is assumed to be strictly lower than β_P. The entrepreneur i maximizes her lifetime utility under the budget constraint:

$$\begin{aligned} & c_t^E(i) + w_t^P l_t^{E,P}(i) + w_t^I l_t^{E,I}(i) + \frac{1+r_{t-1}^{bE}}{\pi_t} b_{t-1}^E(i) + q_t^k k_t^E(i) + \vartheta(u_t(i)) k_{t-1}^E(i) \\ & \leq \frac{y_t^E(i)}{x_t} + b_t^E(i) + q_t^k (1-\delta) k_{t-1}^E(i) \end{aligned} \tag{E6}$$

where δ is the depreciation rate of physical capital k_t^E, b_t^E is loans from banks, u_t is the capital utilization rate, and $l_t^{E,P}(i)$ and $l_t^{E,I}(i)$ are labor inputs for patient and impatient households, respectively. The cost of capital utilization per unit of capital is given by the convex function $\vartheta(u_t(i))$. $x_t = P_t/P_t^W$ is the inverse relative competitive price of the wholesale good y_t^E produced according to the technology

$$y_t^E(i) = \varepsilon_t^a \left[u_t(i) k_{t-1}^E(i)\right]^\alpha \left[l_t^E(i)\right]^{1-\alpha} \tag{E7}$$

where ε_t^a is an exogenous process for total factor productivity. The labor of the two types of households is combined in the production function in a Cobb-Douglas form: $l_t^E = (l_t^{E,P})^\mu (l_t^{E,I})^{1-\mu}$, where μ measures the labor income share of patient households.

Similar to mortgage borrowers, the amount of resources that banks are willing to lend to entrepreneurs is constrained by the value of the collateral, which is given by entrepreneurs' holdings of physical capital, such that the borrowing constraint is given by

$$(1+r_t^{bE}) b_t^E(i) \leq \varepsilon_t^{mE}\, \mathrm{E}_t \left((1-\delta) q_{t+1}^k \pi_{t+1} k_t^E(i)\right) \tag{E8}$$

where ε_t^{mE} is the stochastic entrepreneurs' loan-to-value ratio.

E.3. **Employment agencies.** Workers provide differentiated labor types sold by unions to perfectly competitive employment agencies, which assemble the labor service in a CES aggregator with stochastic parameter ε_t^l and sell homogeneous labor to entrepreneurs. For each labor type m, there are two unions, one for patient households and one for impatient households. Each union sets nominal wages $W_t^\zeta(m)$ (with $\zeta \in \{P, I\}$) for its members by maximizing their utility subject to downward sloping demand and to quadratic adjustment costs (parameterized by κ_w), with indexation ι_w to lagged inflation and $(1-\iota_w)$ to steady-state inflation (noted π). Unions charge their members lump-sum fees to cover adjustment costs with an equal split. They seek to maximize the following expression:

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta_\zeta^t \left\{ \Lambda_t^\zeta(i,m) \left[\frac{W_t^\zeta(m)}{P_t} l_t^\zeta(i,m) - \frac{\kappa_w}{2} \left(\frac{W_t^\zeta(m)}{W_{t-1}^\zeta(m)} - \pi_{t-1}^{\iota_w} \pi^{1-\iota_w} \right)^2 \frac{W_t^\zeta}{P_t} \right] - \frac{l_t^\zeta(i,m)^{1+\phi}}{1+\phi} \right\}, \tag{E9}$$

with $\zeta \in \{P, I\}$, subject to demand from employment agencies

$$l_t^{\zeta}(i,m) = l_t^{\zeta}(m) = \left(\frac{W_t^{\zeta}(m)}{W_t^{\zeta}} \right)^{-\varepsilon_t^l} l_t^{\zeta}, \tag{E10}$$

with $\Lambda_t^{\zeta}(i,m)$ representing the marginal utility of consumption of household i of type ζ with labor type m.

E.4. **Capital and final goods producers.** Capital-producing firms act in a perfectly competitive market and are owned by entrepreneurs. They purchase last period's undepreciated capital $(1-\delta)k_{t-1}$ from the entrepreneurs at a price Q_t^k and i_t units of final goods from retail firms at a price P_t, and then they combine the two to produce new capital. The transformation of the final goods into capital is subject to quadratic adjustment costs. The new capital is then sold back to the entrepreneurs at the same price Q_t^k. The capital producers maximize their expected discounted profits:

$$\max_{\{k_t(i), i_t(i)\}} \mathrm{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^e \left(q_t^k [k_t(i) - (1-\delta)k_{t-1}(i)] - i_t(i) \right) \tag{E11}$$

subject to

$$k_t(i) = (1-\delta)k_{t-1}(i) + \left[1 - \frac{\kappa_i}{2} \left(\frac{\varepsilon_t^{qk} i_t(i)}{i_{t-1}(i)} - 1 \right)^2 \right] i_t(i) \tag{E12}$$

where κ_i denotes the cost of adjusting investment, ε_t^{qk} is an investment shock, $q_t^k = Q_t^k / P_t$ is the real price of capital, and $\Lambda_{0,t}^e$ is the entrepreneurs' stochastic discount factor.

Retailer producers are owned by patient households. They act in monopolistic competition, and their prices are sticky because of the existence of quadratic adjustment costs when prices are revised. They purchase the intermediate (wholesale) good from entrepreneurs in a competitive market and then slightly differentiate it at no additional cost. Each firm $\nu \in (0,1)$ chooses its price to maximize the expected discounted value of profits

$$\max_{\{P_t(\nu)\}} \mathrm{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[\left(P_t(\nu) - P_t^W \right) y_t(\nu) - \frac{\kappa_P}{2} \left(\frac{P_t(\nu)}{P_{t-1}(\nu)} - \pi_{t-1}^{\iota_p} \pi^{1-\iota_p} \right)^2 P_t y_t \right] \tag{E13}$$

subject to the demand derived from consumers' maximization

$$y_t(\nu) = \left(\frac{P_t(\nu)}{P_t} \right)^{-\varepsilon_t^y} y_t \tag{E14}$$

where κ_p denotes the cost of adjusting prices, $\iota_p \in [0,1]$ is the degree of indexation to past inflation, ε_t^y is the stochastic demand price elasticity, P_t^W is the wholesale price and $\Lambda_{0,t}^P$ is the patient households' stochastic discount factor.

E.5. **Monetary policy.** The central bank follows a Taylor-type rule by gradually adjusting the nominal policy rate in response to inflation and output growth:

$$\frac{1+r_t}{1+r} = \left(\frac{1+r_{t-1}}{1+r}\right)^{\phi_R} \left(\frac{\pi_t}{\pi}\right)^{\phi_\pi(1-\phi_R)} \left(\frac{y_t}{y_{t-1}}\right)^{\phi_y(1-\phi_R)} \varepsilon_t^r \tag{E15}$$

where ε_t^r is a monetary policy shock and r is the steady-state value of the policy rate. The parameter ϕ_R captures the degree of interest-rate smoothing, and ϕ_π and ϕ_y are the weights assigned to inflation and output growth, respectively.

E.6. **Market clearing and stochastic processes.** Market clearing conditions in the final goods market are given by

$$y_t = c_t + q_t^k \left[k_t - (1-\delta)k_{t-1}\right] + k_{t-1}\vartheta\left(u_t\right) + \delta^b \frac{K_{t-1}^b}{\pi_t} + \mathcal{A}_t \tag{E16}$$

where $c_t = c_t^P + c_t^I + c_t^E$ is aggregate consumption, k_t is physical aggregate capital, and K_t^b is aggregate bank capital. The term $\mathcal{A}_t$ includes all adjustment costs (i.e., for prices, wages, and interest rates). Equilibrium in the housing market is given by

$$\bar{h} = h_t^P(i) + h_t^I(i), \tag{E17}$$

where $\bar{h}$ is the exogenous fixed housing supply.

Regarding the properties of the stochastic variables, monetary policy shocks evolve according to $log(\varepsilon_t^R/\varepsilon^R) = \xi_t^R$. The remaining exogenous variables follow an AR(1) process such that

$$log(\varepsilon_t^\vartheta/\varepsilon^\vartheta) = \rho_\vartheta log(\varepsilon_{t-1}^\vartheta/\varepsilon^\vartheta) + \xi_t^\vartheta \tag{E18}$$

with $\vartheta = \{a, z, h, l, qk, y, Kb, d, bH, bE, mI, mE\}$. In all cases, $\xi_t^\vartheta \sim i.i.d.\mathcal{N}(0, \sigma_\vartheta^2)$.

Appendix F. Equilibrium conditions

This section reports the first-order conditions for the agents (optimizing problems and the other relationships that define the equilibrium of the model). The variables λ^x_{t+j}, $\forall x = \{I, P, E\}$ and $j = \{0, 1\}$, s^I_t and s^E_t are Lagrange multipliers. $\mathcal{P}^r_t$ represents the profits of retailers in t. A variable without a temporal subscript designates its steady-state value.

Impatient Households

$$c^I_t + q^h_t \left(h^I_t - h^I_{t-1} \right) + \left(1 + r^{bH}_{t-1} \right) b^I_{t-1} / \pi_t = w^I_t l^I_t + b^I_t + \tau^I_t \tag{F1}$$

$$\left(1 + r^{bH}_t \right) b^I_t \leq \varepsilon^{mI}_t \mathrm{E}_t \left[q^h_{t+1} h^I_t \pi_{t+1} \right] \tag{F2}$$

$$\frac{\left(1 - a^I\right) \varepsilon^z_t}{c^I_t - a^I c^I_{t-1}} = \lambda^I_t \tag{F3}$$

$$\lambda^I_t q^h_t = \frac{\varepsilon^h_t}{h^I_t} + \beta_I \mathrm{E}_t \left[\left(\lambda^I_{t+1} q^h_{t+1} + s^I_t \varepsilon^{mI}_t q^h_{t+1} \pi_{t+1} \right) \right] \tag{F4}$$

$$\lambda^I_t = \beta_I \mathrm{E}_t \left[\lambda^I_{t+1} \frac{\left(1 + r^{bh}_t\right)}{\pi_{t+1}} \right] + s^I_t \left(1 + r^{bh}_t \right) \tag{F5}$$

$$\begin{aligned} \kappa_w \left(\pi^{wI}_t - \pi^{\iota_w}_{t-1} \pi^{1-\iota_w} \right) \pi^{wI}_t = \beta_I E_t & \left[\frac{\lambda^I_{t+1}}{\lambda^I_t} \kappa_w \left(\pi^{wI}_{t+1} - \pi^{\iota_w}_t \pi^{1-\iota_w} \right) \frac{\left(\pi^{wI}_{t+1}\right)^2}{\pi_{t+1}} \right] \\ & + \left(1 - \varepsilon^l_t \right) l^I_t + \frac{\varepsilon^l_t \left(l^I_t\right)^{1+\phi}}{w^{wI}_t \lambda^I_t} \end{aligned} \tag{F6}$$

$$\pi^{wI}_t = \frac{w^{wI}_t}{w^{wI}_{t-1}} \pi_t \tag{F7}$$

Patient Households

$$c^P_t + q^h_t \left(h^P_t - h^P_{t-1} \right) + d^P_t = w^P_t l^P_t + \left(1 + r^d_{t-1} \right) d^P_{t-1} / \pi_t + t^P_t \tag{F8}$$

$$\frac{(1 - a^p) \varepsilon^z_t}{c^p_t - a^p c^p_{t-1}} = \lambda^p_t \tag{F9}$$

$$\lambda^P_t q^h_t = \frac{\varepsilon^h_t}{h^P_t} + \beta_P \mathrm{E}_t \left(\lambda^P_{t+1} q^h_{t+1} \right) \tag{F10}$$

$$\lambda_t^P = \beta_P \mathrm{E}_t \left[\lambda_{t+1}^P \frac{(1+r_t^d)}{\pi_{t+1}} \right] \tag{F11}$$

$$\begin{aligned} \kappa_w \left(\pi_t^{wP} - \pi_{t-1}^{\iota_w} \pi^{1-\iota_w} \right) \pi_t^{wP} = \beta_P E_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \kappa_w \left(\pi_{t+1}^{wP} - \pi_t^{\iota_w} \pi^{1-\iota_w} \right) \frac{\left(\pi_{t+1}^{wP}\right)^2}{\pi_{t+1}} \right] \\ + \left(1 - \varepsilon_t^l \right) l_t^P + \frac{\varepsilon_t^l \left(l_t^P \right)^{1+\phi}}{w_t^{wP} \lambda_t^P} \end{aligned} \tag{F12}$$

$$\pi_t^{wP} = \frac{w_t^{wP}}{w_{t-1}^{wP}} \pi_t \tag{F13}$$

Entrepreneurs

$$c_t^E + w_t^P l_t^{E,P} + w_t^I l_t^{E,I} + \left(1 + r_{t-1}^{bE} \right) b_{t-1}^E / \pi_t + q_t^k k_t^E + \vartheta(u_t) k_{t-1}^E = \frac{y_t^E}{x_t} + b_t^E + q_t^k (1-\delta) k_{t-1}^E \tag{F14}$$

$$\vartheta(u_t) = \xi_1 \left(u_t - 1 \right) + \frac{\xi_2}{2} \left(u_t - 1 \right)^2 \tag{F15}$$

$$r_t^k = \xi_1 + \xi_2 \left(u_t - 1 \right) \tag{F16}$$

$$\left(1 + r_t^{bE} \right) b_t^E \leq \varepsilon_t^{mE} E_t \left[q_{t+1}^k k_t^E \pi_{t+1} (1-\delta) \right] \tag{F17}$$

$$\frac{1 - a^E}{c_t^E - a^E c_{t-1}^E} = \lambda_t^E \tag{F18}$$

$$\lambda_t^E = \beta_E \mathrm{E}_t \left[\lambda_{t+1}^E \frac{(1+r_t^{bE})}{\pi_{t+1}} \right] + s_t^E \left(1 + r_t^{bE} \right) \tag{F19}$$

$$\begin{aligned} \lambda_t^E q_t^k = \beta_E \mathrm{E}_t \left\{ \lambda_{t+1}^E \left[r_{t+1}^k u_{t+1} + q_{t+1}^k (1-\delta) - \left(\xi_1 \left(u_{t+1} - 1 \right) + \frac{\xi_2}{2} \left(u_{t+1} - 1 \right)^2 \right) \right] \right\} \\ + \mathrm{E}_t \left[s_t^E \varepsilon_t^{mE} q_{t+1}^k \pi_{t+1} (1-\delta) \right] \end{aligned} \tag{F20}$$

$$y_t^E = \varepsilon_t^a \left[u_t k_{t-1}^E \right]^\alpha \left[\left(l_t^{E,P} \right)^\mu \left(l_t^{E,I} \right)^{1-\mu} \right]^{1-\alpha} \tag{F21}$$

$$w_t^P = \mu (1-\alpha) \frac{y_t^E}{l_t^{E,P}} \frac{1}{x_t} \tag{F22}$$

$$w_t^I = (1-\mu)(1-\alpha) \frac{y_t^E}{l_t^{E,I}} \frac{1}{x_t} \tag{F23}$$

$$r_t^k = \alpha \varepsilon_t^a \left[u_t k_{t-1}^E\right]^{\alpha-1} \left[\left(l_t^{E,P}\right)^{\mu} \left(l_t^{E,l}\right)^{1-\mu}\right]^{1-\alpha} \frac{1}{x_t} \tag{F24}$$

Capital Producers

$$k_t = (1-\delta)k_{t-1} + \left[1 - \frac{\kappa_i}{2}\left(\frac{i_t \varepsilon_t^{qk}}{i_{t-1}} - 1\right)^2\right] i_t \tag{F25}$$

$$\begin{aligned} 1 = {} & q_t^k \left[1 - \frac{\kappa_i}{2}\left(\frac{i_t \varepsilon_t^{qk}}{i_{t-1}} - 1\right)^2 - \kappa_i \left(\frac{i_t \varepsilon_t^{qk}}{i_{t-1}} - 1\right)\frac{i_t \varepsilon_t^{qk}}{i_{t-1}}\right] \\ & + \beta_E E_t \left[\frac{\lambda_{t+1}^E}{\lambda_t^E} q_{t+1}^k \kappa_i \left(\frac{i_{t+1}\varepsilon_{t+1}^{qk}}{i_t} - 1\right) \varepsilon_{t+1}^{qk} \left(\frac{i_{t+1}}{i_t}\right)^2\right] \end{aligned} \tag{F26}$$

Final Goods Producers (Retailers)

$$\mathcal{P}_t^r = y_t \left(1 - \frac{1}{x_t}\right) - \frac{\kappa_P}{2}\left(\pi_t - \pi_{t-1}^{\iota_P}\pi^{1-\iota_P}\right)^2 \tag{F27}$$

$$\begin{aligned} 0 &= 1 - \varepsilon_t^y + \frac{\varepsilon_t^y}{x_t} - \kappa_P \left(\pi_t - \pi_{t-1}^{\iota_P}\pi^{1-\iota_P}\right)\pi_t \\ &+ \beta_P E_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P}\kappa_P \left(\pi_{t+1} - \pi_t^{\iota_P}\pi^{1-\iota_P}\right)\pi_{t+1}\frac{y_{t+1}}{y_t}\right] \end{aligned} \tag{F28}$$

Banks' Retail Units

$$\begin{aligned} 0 = {} & 1 - \varepsilon_t^{bE} + \varepsilon_t^{bE}\frac{R_t^b}{r_t^{bE}} - \left(\kappa_{bE}\left(\frac{r_t^{bE}}{r_{t-1}^{bE}} - 1\right) + \frac{1}{\psi_{bE}}\left\{1 - \exp\left[-\psi_{bE}\left(\frac{r_t^{bE}}{r_{t-1}^{bE}} - 1\right)\right]\right\}\right)\frac{r_t^{bE}}{r_{t-1}^{bE}} \\ & + \beta_P \mathrm{E}_t \left\{\left(\kappa_{bE}\left(\frac{r_{t+1}^{bE}}{r_t^{bE}} - 1\right) + \frac{1}{\psi_{bE}}\left\{1 - \exp\left[-\psi_{bE}\left(\frac{r_{t+1}^{bE}}{r_t^{bE}} - 1\right)\right]\right\}\right)\frac{\lambda_{t+1}^P}{\lambda_t^P}\left(\frac{r_{t+1}^{bE}}{r_t^{bE}}\right)^2 \frac{b_{t+1}^E}{b_t^E}\right\} \end{aligned} \tag{F29}$$

$$\begin{aligned} 0 = {} & 1 - \varepsilon_t^{bH} + \varepsilon_t^{bH}\frac{R_t^b}{r_t^{bH}} - \left(\kappa_{bH}\left(\frac{r_t^{bH}}{r_{t-1}^{bH}} - 1\right) + \frac{1}{\psi_{bH}}\left\{1 - \exp\left[-\psi_{bH}\left(\frac{r_t^{bH}}{r_{t-1}^{bH}} - 1\right)\right]\right\}\right)\frac{r_t^{bH}}{r_{t-1}^{bH}} \\ & + \beta_P \mathrm{E}_t \left\{\left(\kappa_{bH}\left(\frac{r_{t+1}^{bH}}{r_t^{bH}} - 1\right) + \frac{1}{\psi_{bH}}\left\{1 - \exp\left[-\psi_{bH}\left(\frac{r_{t+1}^{bH}}{r_t^{bH}} - 1\right)\right]\right\}\right)\frac{\lambda_{t+1}^P}{\lambda_t^P}\left(\frac{r_{t+1}^{bH}}{r_t^{bH}}\right)^2 \frac{b_{t+1}^H}{b_t^H}\right\} \end{aligned} \tag{F30}$$

$$0 = 1 - \varepsilon^d + \varepsilon^d \frac{r_t}{r_t^d} + \kappa_d \left(\frac{r_t^d}{r_{t-1}^d} - 1 \right) \frac{r_t^d}{r_{t-1}^d} + \beta_P E_t \left[\kappa_d \frac{\lambda_{t+1}^P}{\lambda_t^P} \left(\frac{r_{t+1}^d}{r_t^d} - 1 \right) \left(\frac{r_{t+1}^d}{r_t^d} \right)^2 \frac{d_{t+1}^P}{d_t^P} \right] \tag{F31}$$

Banks' Wholesale Units

$$B_t \equiv b_t^H + b_t^E = D_t + K_t^b \tag{F32}$$

$$\pi_t K_t^b = (1 - \delta_b) \frac{K_{t-1}^b}{\varepsilon_t^{Kb}} + \mathcal{P}_{t-1}^b \tag{F33}$$

$$R_t^b = r_t - \kappa_{Kb} \left(\frac{K_t^b}{B_t} - \nu_t \right) \left(\frac{K_t^b}{B_t} \right)^2 \tag{F34}$$

$$\begin{aligned} \mathcal{P}_t^b = {} & r_t^{bH} b_t^H + r_t^{bE} b_t^E - r_t^d d_t - \frac{\kappa_{Kb}}{2} \left(\frac{K_t^b}{B_t} - \nu_t \right)^2 K_t^b - \frac{\kappa_d}{2} \left(\frac{r_t^d}{r_{t-1}^d} - 1 \right)^2 r_t^d d_t \\ & - \left\{ \frac{\kappa_{bE}}{2} \left(\frac{r_t^{bE}}{r_{t-1}^{bE}} - 1 \right)^2 + \frac{1}{\psi_{bE}^2} \left\{ \exp \left[-\psi_{bE} \left(\frac{r_t^{bE}}{r_{t-1}^{bE}} - 1 \right) \right] + \psi_{bE} \left(\frac{r_t^{bE}}{r_{t-1}^{bE}} - 1 \right) - 1 \right\} \right\} r_t^{bE} b_t^E \\ & - \left\{ \frac{\kappa_{bH}}{2} \left(\frac{r_t^{bH}}{r_{t-1}^{bH}} - 1 \right)^2 + \frac{1}{\psi_{bH}^2} \left\{ \exp \left[-\psi_{bH} \left(\frac{r_t^{bH}}{r_{t-1}^{bH}} - 1 \right) \right] + \psi_{bH} \left(\frac{r_t^{bH}}{r_{t-1}^{bH}} - 1 \right) - 1 \right\} \right\} r_t^{bH} b_t^H \end{aligned} \tag{F35}$$

Monetary Policy

$$\frac{1 + r_t}{1 + r} = \left(\frac{1 + r_{t-1}}{1 + r} \right)^{\phi_R} \left(\frac{\pi_t}{\pi} \right)^{\phi_\pi (1 - \phi_R)} \left(\frac{y_t}{y_{t-1}} \right)^{\phi_y (1 - \phi_R)} \varepsilon_t^r \tag{F36}$$

Market Clearing and Identities

$$Y_t = c_t^P + c_t^I + c_t^E + k_t - (1 - \delta) k_{t-1} \tag{F37}$$

$$y_t^E = y_t, \quad l_t^{E,P} = l_t^P, \quad l_t^{E,I} = l_t^I, \quad 1 = h_t^P + h_t^I, \quad d_t^P = D_t, \quad k_t^E = K_t \tag{F38}$$

Exogenous Shocks

$$log(\varepsilon_t^\vartheta / \varepsilon^\vartheta) = \rho_\vartheta log(\varepsilon_{t-1}^\vartheta / \varepsilon^\vartheta) + \xi_t^\vartheta \tag{F39}$$

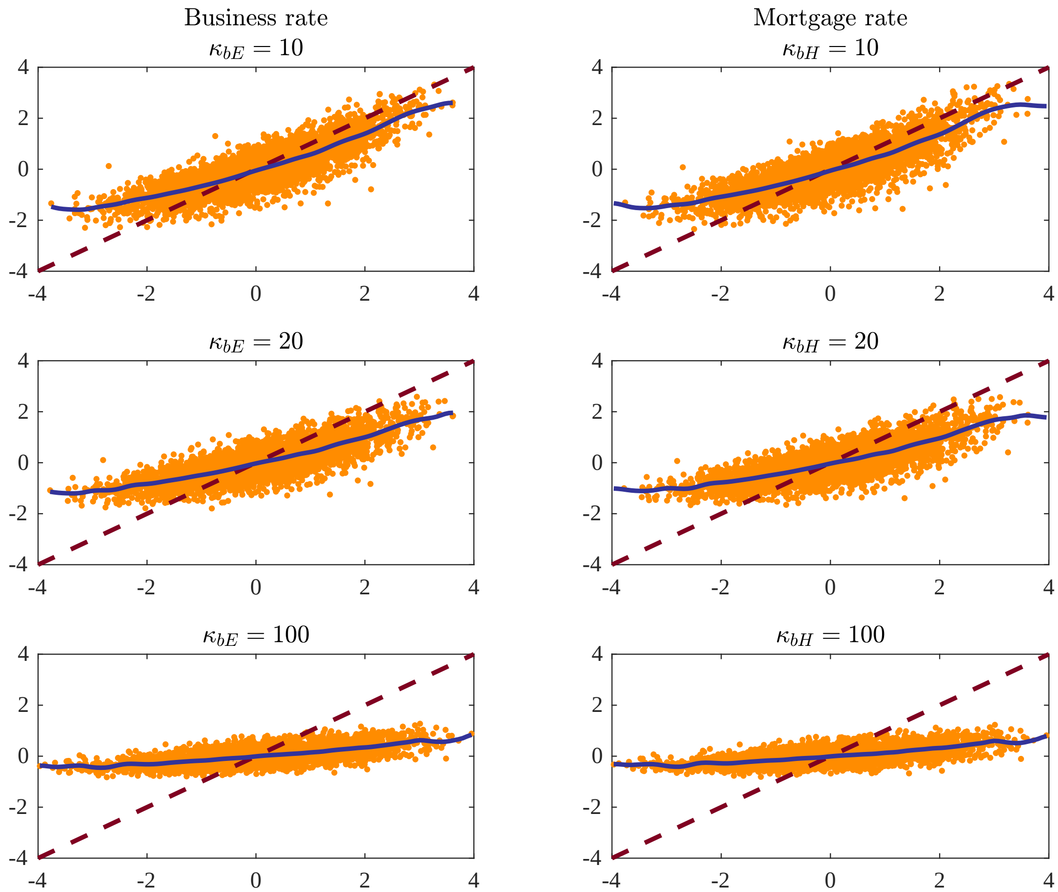
with $\vartheta = \{a, z, h, l, qk, y, Kb, d, bH, bE, mI, mE\}$.

Appendix G. Details on the calibration of the model

Table G1. Calibrated parameters

Parameter	Description	Value
κ_{bE}	Cost of adjusting BLR to entrepreneurs	3.7
κ_{bH}	Cost of adjusting BLR to households	3.6
ψ_{bE}	Asymmetric parameter in BLR adjustment costs - entrepreneurs	95
ψ_{bH}	Asymmetric parameter in BLR adjustment costs - households	105
κ_d	Cost of adjusting deposit rate	3.50
$\varepsilon^{bE}/(\varepsilon^{bE}-1)$	Steady-state markup on BLR to entrepreneurs	3.12
$\varepsilon^{bH}/(\varepsilon^{bH}-1)$	Steady-state markup on BLR to households	2.79
$\varepsilon^{d}/(\varepsilon^{d}-1)$	Steady-state markdown on deposit rate	-1.46
ν^b	Target capital-to-asset ratio	0.09
κ_{Kb}	Cost of adjusting capital-asset ratio	11.07
δ^b	Cost of managing banks' capital position	0.104
β_P	Patient households' discount factor	0.994
β_I	Impatient households' discount factor	0.975
β_E	Entrepreneurs' discount factor	0.975
ϕ	Inverse of the Frisch elasticity	1.0
ε^h	Steady-state weight of housing in households' utility function	0.2
a^P, a^I, a^E	Degree of habit formation in consumption	0.86
ε^{mI}	Steady state LTV ratio for impatient households	0.9
α	Capital share in the production function	0.3
μ	Labor income share of patient households	0.9
ξ_1	Parameter of adjustment cost for capacity utilization	0.04
ξ_2	Parameter of adjustment cost for capacity utilization	0.004
ε^{mE}	Steady-state LTV ratio for entrepreneurs	0.9
κ_w	Cost for adjusting nominal wages	99.90
ι_w	Indexation of nominal wages to past inflation	0.28
$\varepsilon^{l}/(\varepsilon^{l}-1)$	Steady-state markup in the labor market	1.25
δ	Depreciation rate of physical capital	0.025
κ_i	Cost for adjusting investment	10.18
κ_P	Cost for adjusting good prices	28.65
ι_p	Indexation of prices to past inflation	0.16
$\varepsilon^{y}/(\varepsilon^{y}-1)$	Steady-state markup in the goods market	1.2
ϕ_R	Interest rate smoothing in the policy rule	0.77
ϕ_π	Reaction parameter to inflation in the policy rule	1.98
ϕ_y	Reaction parameter to output growth in the policy rule	0.35
ρ_z ; σ_z	Persistence and std deviation - preference shock	0.39 ; 0.027
ρ_h ; σ_h	Persistence and std deviation - housing preference shock	0.92 ; 0.071
ρ_{mE} ; σ_{mE}	Persistence and std deviation - firms' LTV shock	0.89 ; 0.007
ρ_{mI} ; σ_{mI}	Persistence and std deviation - households' LTV shock	0.93 ; 0.003
ρ_d ; σ_d	Persistence and std deviation - deposit markdown shock	0.84 ; 0.032
ρ_{bE} ; σ_{bE}	Persistence and std deviation - BLR markup shock (entrepreneurs)	0.83 ; 0.063
ρ_{bH} ; σ_{bH}	Persistence and std deviation - BLR markup shock (households)	0.82 ; 0.066
ρ_a ; σ_a	Persistence and std deviation - technology shock	0.94 ; 0.006
ρ_{qk} ; σ_{qK}	Persistence and std deviation - investment efficiency shock	0.55 ; 0.019
ρ_y ; σ_y	Persistence and std deviation - price markup shock	0.30 ; 0.598
ρ_w ; σ_w	Persistence and std deviation - wage markup shock	0.64 ; 0.561
ρ_{Kb} ; σ_{Kb}	Persistence and std deviation - banks' capital shock	0.81 ; 0.031
σ_r	Std deviation - monetary policy shock	0.002

FIGURE G1. Simulated changes in the policy rate and BLRs



Note: The scatter plots are based on 4000 simulations of the asymmetric model (all shocks included) for different values of κ_{bs}. The solid blue line represents the nonparametric regression. Horizons in quarters.