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Monetary Policy Transmission with Downward Interest Rate Rigidity

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MONETARY POLICY TRANSMISSION WITH DOWNWARD INTEREST RATE RIGIDITY

GREGORY LEVIEUGE AND JEAN-GUILLAUME SAHUC

ABSTRACT. Empirical evidence suggests that the pass-through from policy to retail bank rates is asymmetric in the euro area. Bank lending rates adjust more slowly and less completely to Eonia decreases than to increases. We investigate how this downward interest rate rigidity affects the response of the economy to monetary policy shocks. To this end, we introduce asymmetric bank lending rate adjustment costs in a macrofinance dynamic stochastic general equilibrium model. We find that the initial response of GDP to a negative monetary policy shock is 25% lower than its response to a positive shock of similar amplitude. This implies that a central bank would have to decrease its policy rate by 50% to 75% more to obtain a medium-run impact on GDP that would be symmetric to the impact of the positive shock. 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.

JEL: E32, E44, E52.

Keywords: Downward interest rate rigidity, asymmetric adjustment costs, banking sector, DSGE model, euro area.

1. INTRODUCTION

The adjustment of bank lending rates in response to changes in policy rates is a key element of the monetary policy transmission mechanism. This is especially true for the euro area, where the external financing of households and firms consists, to a large extent, of loans originated and held by banks. Therefore, carefully considering all the characteristics of the interest rate channel is essential for assessing the effectiveness of monetary policy. Standard practice in structural macroeconomic modeling is to assume that the interest rate pass-through is either complete or symmetrically limited. However, empirical evidence from banking data suggests that banks tend to adjust their lending rates more slowly and not 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 policy rates. What are the effects of neglecting this downward interest rate rigidity?

February 2020. G. Levieuge: Banque de France, 31 rue Croix des Petits Champs, 75049 Paris, France and Univ. Orléans, CNRS, LEO, FRE2014, F-45067, Orléans, France. (e-mail: gregory.levieuge@banque-france.fr). J.-G. Sahuc: Banque de France, 31 rue Croix des Petits Champs, 75049 Paris, France (e-mail: jean-guillaume.sahuc@banque-france.fr). We thank Stephane Dupraz, Erwan Gautier, Paolo Gelain, Alexander Guembel, Guillaume Horny, Michel Juillard, Patrick Kehoe, Julien Matheron, Frank Smets, Ulf Soderstrom, Mirko Wiederholt, Cynthia Wu, Francesco Zanetti and the participants of several conferences for their useful comments and suggestions. The views expressed in this paper are those of the authors and do not necessarily reflect the views of the Banque de France or the Eurosystem.

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 consequences of downward interest rate rigidity for monetary policy effectiveness and macroeconomic stabilization in the euro area.

There are several theoretical motivations for explaining downward interest rate rigidity at the bank level. The first is the presence of *adjustment costs* that restrain banks from making frequent price adjustments and can imply sign-driven asymmetries. This is the case for menu costs, i.e., the costs associated with advertising new price lists, communicating with customers, etc. (Rotemberg and Saloner, 1987). In this context, banks decrease their rates only if the benefits of doing so are greater than the costs of changing them. The second argument relates to *bank concentration*, which leads to oligopolistic behaviors (Berger and Hannan, 1989). Banks in concentrated markets can postpone or at least partially renounce lower lending rates to increase their profit margins. Furthermore, it is costly to break collusive arrangements; thus, the risk of triggering a price war through rate reductions implies costly downward revisions. A third argument is based on *customer switching costs*, which give banks an additional degree of market power (Klemperer, 1995). 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). As a consequence, 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 negative shock. In contrast, when market rates increase, banks may more quickly raise their lending rates, thereby maintaining or increasing their mark-up. 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 all these theoretical causes of rigidity are relatively close to the explanations provided in the literature on sticky prices.

Quantifying 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.¹ 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. The model is solved by second-order perturbation methods to capture the nonlinearities coming from asymmetric adjustment costs and applies the pruning approach of [Kim et al. \(2008\)](#) to guarantee stability of approximations up to the second order of accuracy.

Therefore, we propose a comparison of the effects of a monetary policy shock on the real economy in the presence of interest rate asymmetry. We find that the initial response of GDP to a negative monetary policy shock is 25% lower than its response to a positive shock of similar amplitude. This difference narrows with the horizon but remains significant for a long time. 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.² Our results imply that a central bank would have to decrease its policy rate by 50% to 75% more to yield a medium-run impact on GDP that is symmetric to the impact of a positive 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

¹Such a convex function is used by [Kim and Ruge-Murcia \(2009\)](#) and [Abbritti and Fahr \(2013\)](#) to model asymmetric wage adjustments.

²The 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.*”. [Tenreiro 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.

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 aggregates.³ 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 discusses our empirical results on the quantification of the 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, lending rates to households for house purchase, and Eonia. 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 we use come from the European Central Bank (ECB) Statistical Data Warehouse and are available from January 1999 to December 2018, except for the mortgage rates, which are not available before January

³See among others, [Carlstrom and Fuerst \(1997\)](#), [Bernanke et al. \(1999\)](#), [Iacoviello \(2005\)](#), [Iacoviello and Neri \(2010\)](#), [Gertler and Karadi \(2011\)](#), or [Carlstrom et al. \(2017\)](#).

2003 (full details are available in Appendix A). Our investigation focuses on the period running from January 2003 to June 2012. 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. The dynamics and pass-through of interest rates when they are at their effective lower bound deserve a specific analysis, which is carried out in Section 6. However, we first aim to describe the main characteristics of monetary policy transmission in a “normal” context of positive interest rates. 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 our analysis focuses on bank lending rates because we did not find evidence of asymmetry in the evolution of banks’ deposit rates. Details on deposit rates are provided in Appendix B.

2.1. Fact 1: The positive skewness of bank lending rates. A simple method of assessing asymmetric adjustments of a variable consists of examining its skewness. In particular, 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

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

Note: Skewness is computed over the period 1999-2007 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.

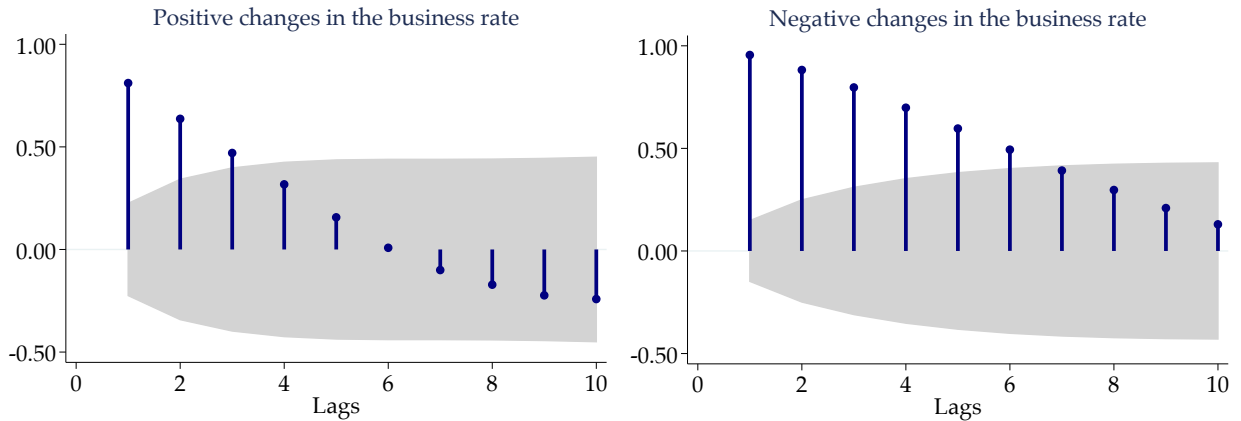
Table 1 summarizes the evidence on skewness of year-on-year changes in business and mortgage BLRs for the euro area and the United States. Turning to the main findings, we observe that BLRs are positively skewed on normal times, i.e., apart from the financial crisis.⁴ Indeed, we obtain a skewness of business BLR of 0.45 in the euro area, 0.61 for France and 0.45 for 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 zone; we also find a positive skewness in the United States over a longer period, from 1975 to 2007.

⁴Obviously, 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 cuts in the policy rate, as indicated in Table C1 in Appendix C. The skewness 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.

It is important to emphasize 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 skewness of BLRs has more direct and crucial implications for the transmission of monetary policy. This point is addressed below.

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 positive autocorrelation when ΔBLR (both business and mortgage) decrease in comparison to when they increase. This suggests more downward than upward sluggishness.

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.

We can formally test the asymmetric autoregressive behavior of the BLR for business 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 $I(\cdot)$ be a dummy variable that is equal to 1 if $\Delta BLR_{t-1} > \zeta$ and 0 otherwise, with ζ as the endogenous threshold parameter, we obtain the following estimate:

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

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.⁵ Second, regime switching is found around a threshold that is very close to zero ($\xi = -0.01$). Third, the downward persistence of the BLR is found to be approximately three times higher than its upward persistence (0.72 versus 0.28). This confirms the former intuition on the downward inertia of BLRs. Similar results are found for France, Germany and the US (see Table C2 in Appendix C).

2.2. Fact 2: Asymmetric interest rate pass-through of monetary policy. The previous observations suggest that bank lending rates adjust asymmetrically to shocks. This may prevail, in particular, in the case of monetary policy shocks, which are key drivers for BLRs. Furthermore, given the importance of bank-based financing in the euro area, the adjustment of BLRs in response to changes in policy rates is crucial for the effectiveness of monetary policy transmission. Consequently, we now focus on the bank lending and policy rates nexus.

FIGURE 2. Year-on-year changes in bank lending rate–Eonia spreads (percent)

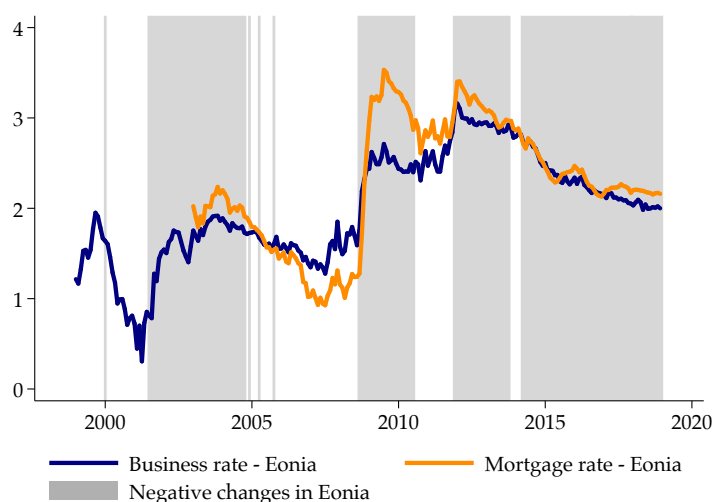


Figure 2 represents the spread between the business bank lending rate and Eonia and the spread between the mortgage rate and Eonia since 1999. The gray shaded areas depict periods of decreasing Eonia. Globally, we can observe that the spreads tend to increase (decrease) when the policy rate decreases (increases). More precisely, the spreads declined over 2000-2002 and 2005-2008, while Eonia was rising. In contrast, the spreads increased over 2002-2004, while Eonia was decreasing. Similarly, we can see a very large increase in the spreads in 2008-2010, following the dramatic cuts in policy rates. The business rate–Eonia spread did not truly decrease afterwards, while the mortgage rate–Eonia spread started to decline in late 2009. Since the global financial crisis, we again have observed a

⁵Estimates 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.

rise of the spreads in the wake of the drop in policy rates in 2011. Nonetheless, as monetary policy has been more accommodative than ever, in terms of both duration and level of policy rates, eventually the spreads have slowly declined. This figure illustrates the smooth downward response of BLRs, i.e., with both sluggishness and asymmetry.

To further study the BLR–policy rate nexus, Table 2 reports the skewness of the difference between the year-on-year change in bank lending rates and the year-on-year change in Eonia. Once again, we focus on the period 2004-2012 for the euro area, which is guided by both the data availability of mortgage rates and the exclusion of the period of the effective lower bound for the policy rate. 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).⁶

TABLE 2. Skewness of the difference of year-on-year changes in BLRs and year-on-year changes in the policy rate

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

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

Our last piece of evidence comes from Figure 3, which reports the scatter points of the changes in BLRs and Eonia. This figure shows that the scatter points deviate significantly from the 45-degree line (which would imply a one-to-one response of BLRs to Eonia), essentially in the area of negative changes. This suggests that BLRs respond more strongly (and possibly more quickly) to policy rate increases than to policy rate cuts.⁷

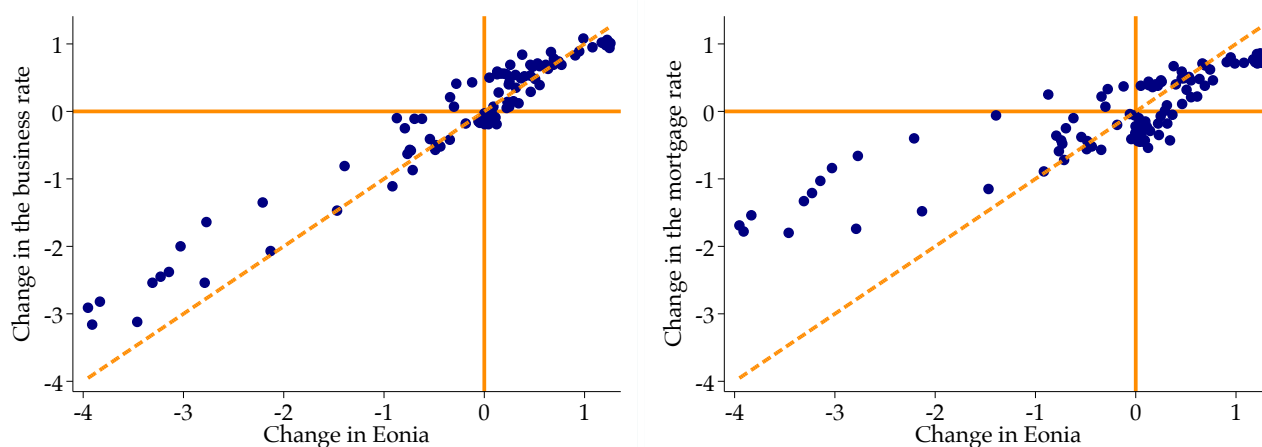
This asymmetric pass-through of monetary policy has given rise to a vast empirical literature that has yielded mixed results.⁸ The latter may be the consequence of model misspecifications: empirical analyses usually test for asymmetric (short- and long-run) elasticity of BLRs to the policy rate, whereas our previous evidence suggests that it is the autoregressive process of BLRs itself that evolves asymmetrically. Furthermore, empirical studies do not address the critical issue of the endogeneity of the

⁶Since the United States experienced a rate hike from December 2015, the sample is extended to 2018.

⁷Similar results are found for the United States; see Appendix D.

⁸See, for instance, [Mojon \(2000\)](#), [Sander and Kleimeier \(2004\)](#), [Kwapil and Scharler \(2010\)](#) and [Belke et al. \(2013\)](#) for the euro area and [Mester and Saunders \(1995\)](#) for the United States.

FIGURE 3. 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.

policy rate. This rate is assumed to be exogenous when estimating the pass-through, while central banks adjust the stance of monetary policy according to the effectiveness of the transmission of policy rates to BLRs. These limits call for an analysis based on a structural approach.

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.

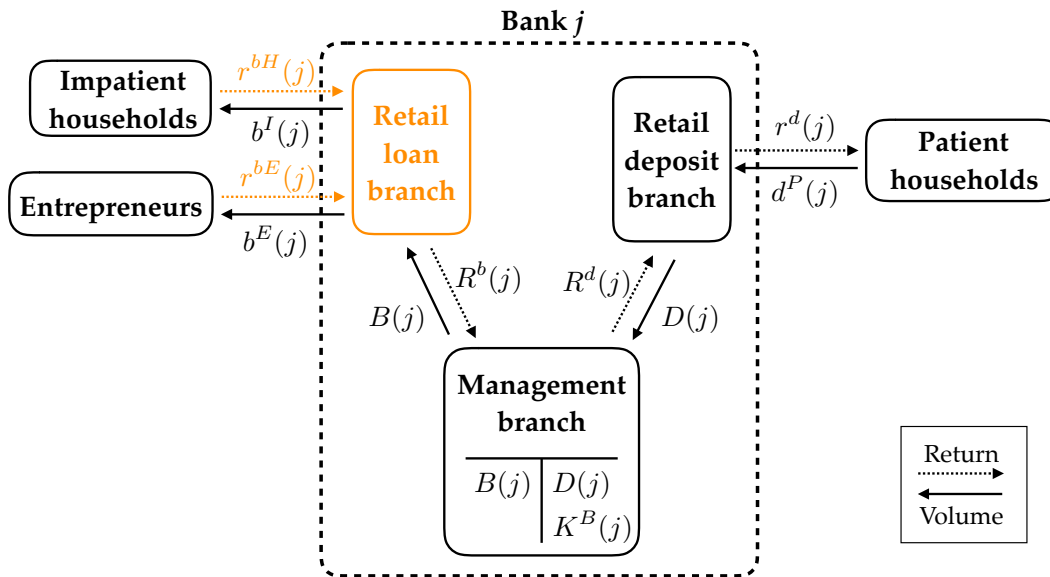
Households maximize a separable utility function in consumption, labor effort and housing over an infinite life horizon. Consumption appears in the utility function relative to a time-varying external habit that depends on past aggregate consumption. Housing is in fixed supply and is traded among households. 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. 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.

FIGURE 4. Schematic of the banking sector



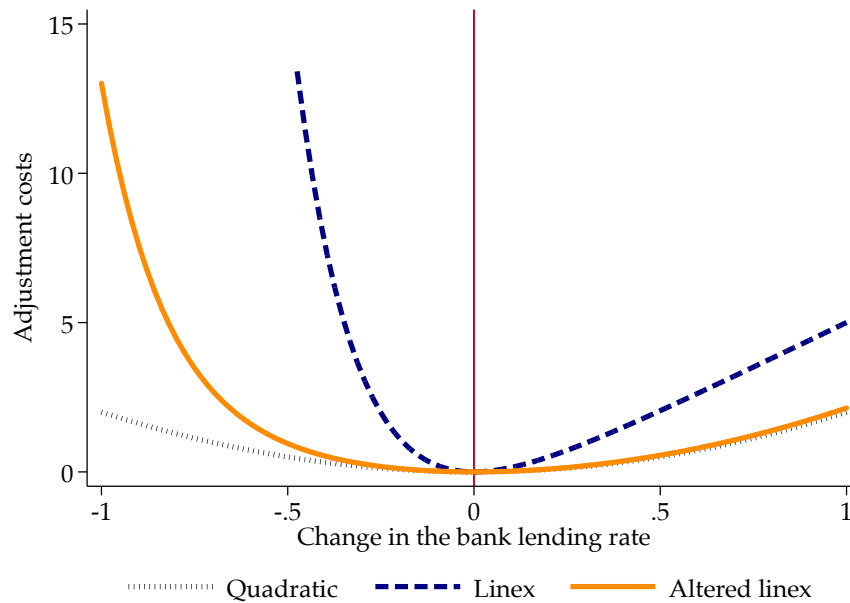
Note: r^i , where $i = \{bH, bE, d\}$, denotes returns received from (paid to) final borrowers (deposit holders). R^d and R^b denote internal returns.

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 4. We elaborate the problems faced by these branches next.

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 two 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.

FIGURE 5. Quadratic, linex and altered linex adjustment cost functions



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 \(2013\)](#):

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

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 $\psi_{bs} \rightarrow 0$. [Figure 5](#) 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. 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

$$\max_{\{r_t^{bH}(j), r_t^{bE}(j)\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[\sum_{s=E,H} \left(r_t^{bs}(j) b_t^s(j) - \mathcal{A}_{bs} \left(\frac{r_t^{bs}(j)}{r_{t-1}^{bs}(j)} \right) r_t^{bs} b_t^s \right) - R_t^b(j) B_t(j) \right], \quad (3)$$

subject to Dixit-Stiglitz loan demand curves

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

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:

$$\begin{aligned} 0 &= 1 - \varepsilon_t^{bs} + \varepsilon_t^{bs} \frac{R_t^b}{r_t^{bs}} - \left(\kappa_{bs} \left(\frac{r_t^{bs}}{r_{t-1}^{bs}} - 1 \right) + \frac{1}{\psi_{bs}} \left\{ 1 - \exp \left[-\psi_{bs} \left(\frac{r_t^{bs}}{r_{t-1}^{bs}} - 1 \right) \right] \right\} \right) \frac{r_t^{bs}}{r_{t-1}^{bs}} \\ &+ \beta P E_t \left\{ \left(\kappa_{bs} \left(\frac{r_{t+1}^{bs}}{r_t^{bs}} - 1 \right) + \frac{1}{\psi_{bs}} \left\{ 1 - \exp \left[-\psi_{bs} \left(\frac{r_{t+1}^{bs}}{r_t^{bs}} - 1 \right) \right] \right\} \right) \frac{\lambda_{t+1}^P}{\lambda_t^P} \left(\frac{r_{t+1}^{bs}}{r_t^{bs}} \right)^2 \frac{b_{t+1}^s}{b_t^s} \right\}, \end{aligned} \quad (5)$$

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.

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:

$$\max_{\{r_t^d(j)\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[R_t^d(j) D_t(j) - r_t^d(j) d_t^P(j) - \mathcal{A}_d \left(\frac{r_t^d(j)}{r_{t-1}^d(j)} \right) r_t^d d_t \right], \quad (6)$$

subject to the Dixit-Stiglitz deposit demand curve

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

where d_t is the aggregate deposits in the economy and $r_t^d = \left[\int_0^1 r_t^d(j)^{1-\varepsilon_t^d} dj \right]^{\frac{1}{1-\varepsilon_t^d}}$ 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:

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

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:

$$\max_{\{B_t(j), D_t(j)\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[R_t^b(j) B_t(j) - R_t^d(j) D_t(j) - \mathcal{A}_{Kb} \left(\frac{K_t^b(j)}{B_t(j)} \right) K_t^b(j) \right]. \quad (9)$$

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

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

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, $R_t^d(j) = r_t, \forall j$.

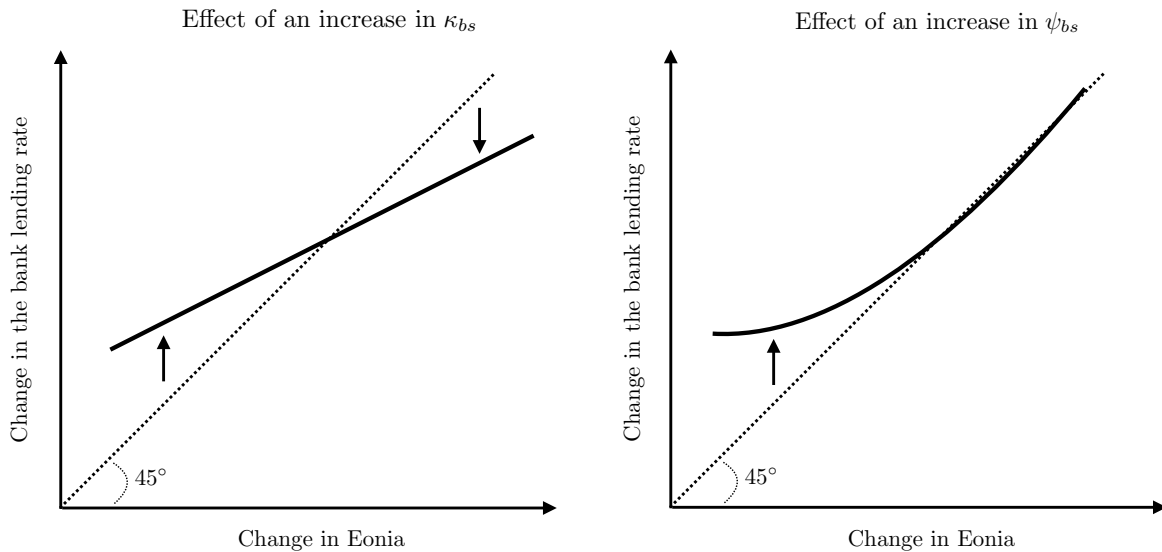
Finally, the overall profits of banking group j are the sum of earnings from the management branch and the two retail branches. After deleting intragroup transactions, overall profits are given by:

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

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 a few exceptions. The first relates to the steady-state loan-to-value ratios associated with impatient households and entrepreneurs, which are set to 0.9 (instead of 0.3), 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](#)). We also reduce the steady-state markups of BLR to 1.11 to not exaggerate the macroeconomic influences of the frictions in the banking sector. We also decrease the weight of housing in households' utility function to 5%. By attenuating the effects of bank behavior on the economy, these changes will make the results from the model simulations rather conservative.

Next, particular attention is paid to the calibration of the parameters associated with the adjustment cost function. As illustrated by [Figure 6](#), 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 with application of the pruning approach suggested by [Kim et al. \(2008\)](#) to guarantee stability of approximations up to the second order of accuracy. This methodology is suitable to capture the nonlinearities embedded in the model. The second and third moments of the year-on-year change in bank lending rates are

FIGURE 6. The effect of κ_{bs} and ψ_{bs} on the Eonia–bank lending rate nexus

generated on the basis of 1000 samples of 40 periods.⁹ 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: $(\kappa_{bE}, \psi_{bE}) = (6, 230)$ and $(\kappa_{bH}, \psi_{bH}) = (6, 260)$.¹⁰ The values of all model parameters are reported in Table G1 of Appendix G.

TABLE 3. Skewness and variance of year-on-year bank lending rates in the data and models

	Data ⁽¹⁾	Asymmetric model	Symmetric model	Gerali <i>et al.</i> model
Skewness of the change in the business rate	0.45	0.38	0.00	−0.10
Skewness of the change in the mortgage rate	0.56 - 0.64	0.39	−0.03	−0.11
Variance of the change in the business rate	0.45	0.44	0.31	0.32
Variance of the change in the mortgage rate	0.47 - 0.68	0.50	0.32	0.31

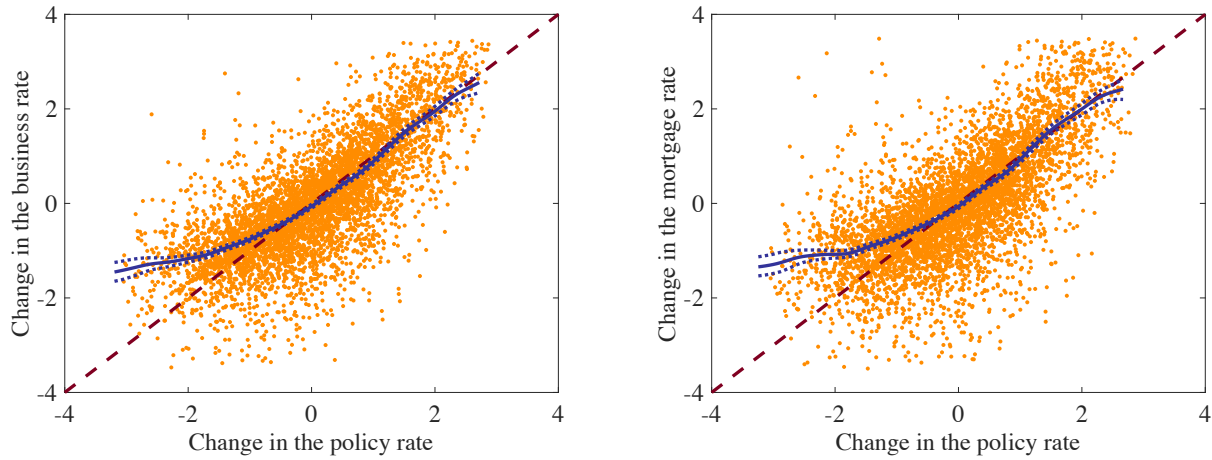
(1) For mortgage rates, the range refers to data for France and Germany.

⁹To have different starting points, we simulate as a presample an additional 460 periods that are not included for the computation of the moments.

¹⁰Note 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.

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 3 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 business and mortgage BLRs observed in the data quite well. In comparison, the symmetric and Gerali et al. (2010) versions generate weaker variances and, more importantly, null or negative skewness. The parameters governing the adjustment cost function of the mortgage rate could be pushed up further to fit the empirical moments even more closely, but a 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.

FIGURE 7. Simulated changes in the policy rate and bank lending rates (percent)



Note: The scatter plot is based on 5000 simulations of the asymmetric model. The solid blue line represents the nonparametric regression, and the thick dashed lines delineate the 90% confidence interval obtained by standard bootstrap techniques.

Second, our asymmetric model also matches well with the empirical BLR–Eonia nexus. Figure 7 reports the relationship between year-on-year changes in BLRs and of the policy rate, based on 5000 simulations of the model. 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 3.

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.

5. ASSESSING THE MACROECONOMIC EFFECTS OF DOWNWARD INTEREST RATE RIGIDITY

5.1. Asymmetric responses to monetary policy shock and nonlinear pass-through. To study the macroeconomic consequences of downward interest rate rigidity, we first analyze the dynamic responses of different variables to positive and negative monetary policy shocks of equal size (60 basis points away from the steady state). These impulse responses are reported in Figure 8, where 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.

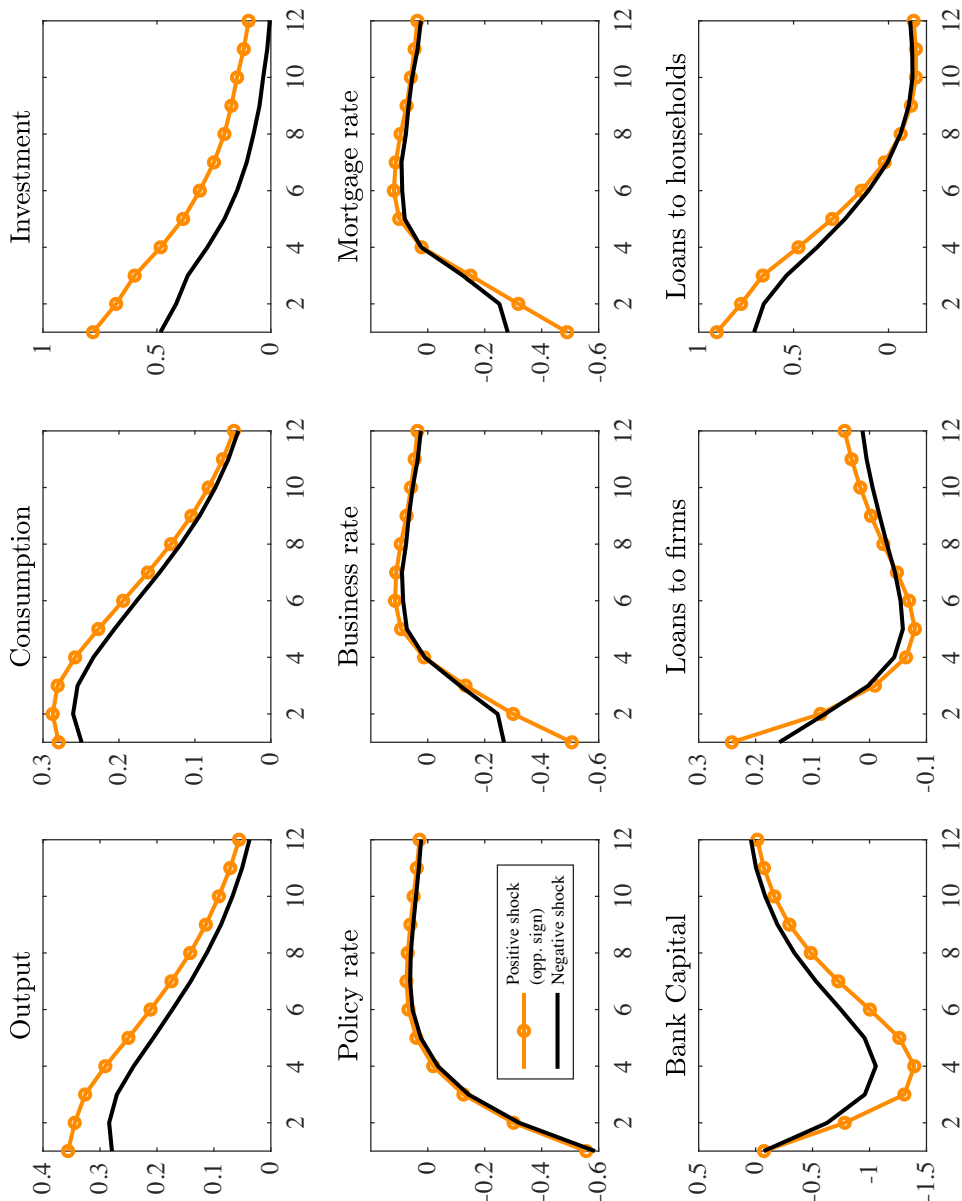
Figure 8 shows that the asymmetric properties of the nonlinear model are consistent with the empirical facts presented in Section 2. Indeed, while the transmission channels are the same, irrespective of the sign of the initial monetary policy shock, the amplitude of the responses is clearly different.

On the one hand, we can observe 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 eq. 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.¹¹ 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 15% and 40% less, respectively, than they decrease in the case of a positive shock.

Finally, the output increase is approximately 25% lower than the output decline that is obtained in the case of a positive shock of similar amplitude. It represents a loss of approximately 11 billion euros of 2018 GDP when the shock occurs and a cumulated GDP difference of approximately 87 billion euros of 2018 GDP over a four-year horizon. Thus, despite a rather conservative calibration with respect to the asymmetry, we find that downward interest rate rigidity has significant macroeconomic effects.

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

FIGURE 8. Monetary policy shock



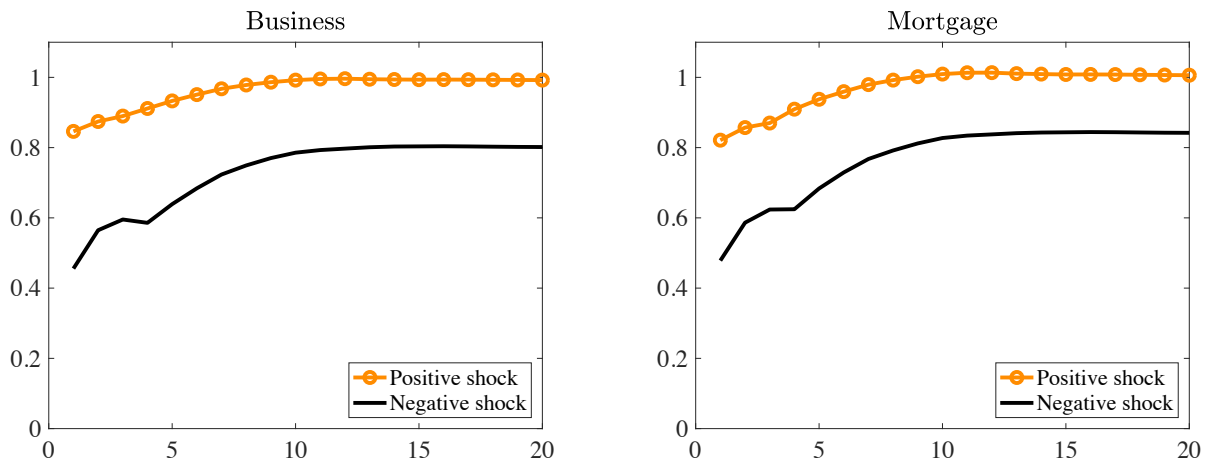
Note: Horizon in quarters. The simulation shows the dynamic responses to positive and negative monetary policy shocks of equal size (60 basis points away from the steady state). The positive shock is shown in the opposite sign to facilitate comparison.

Next, the impulse responses of BLRs can be used to compute the interest rate pass-through to monetary policy shocks. We deliberately focus on monetary policy shocks, although the overall pass-through naturally depends on the various shocks that affect an economy (below, we discuss further the macroeconomic effects following other shocks). Monetary policy pass-through is then measured as a ratio of the cumulated impulse responses over a specific horizon T as follows:

$$\frac{\sum_{t=0}^T |\tilde{r}_t^{bs}(\pm \varepsilon_0^r)|}{\sum_{t=0}^T |\tilde{r}_t(\pm \varepsilon_0^r)|} \quad (12)$$

where $\tilde{r}_t^{bs}(\pm \varepsilon_0^r)$ and $\tilde{r}_t(\pm \varepsilon_0^r)$ are the impulse responses for the bank lending rate of type $s = \{E, H\}$ and the policy rate, respectively, t periods after the monetary policy shock ε_0^r positively or negatively affects the economy. Taking the absolute value makes it possible to correct potential sign changes.

FIGURE 9. Monetary policy pass-through



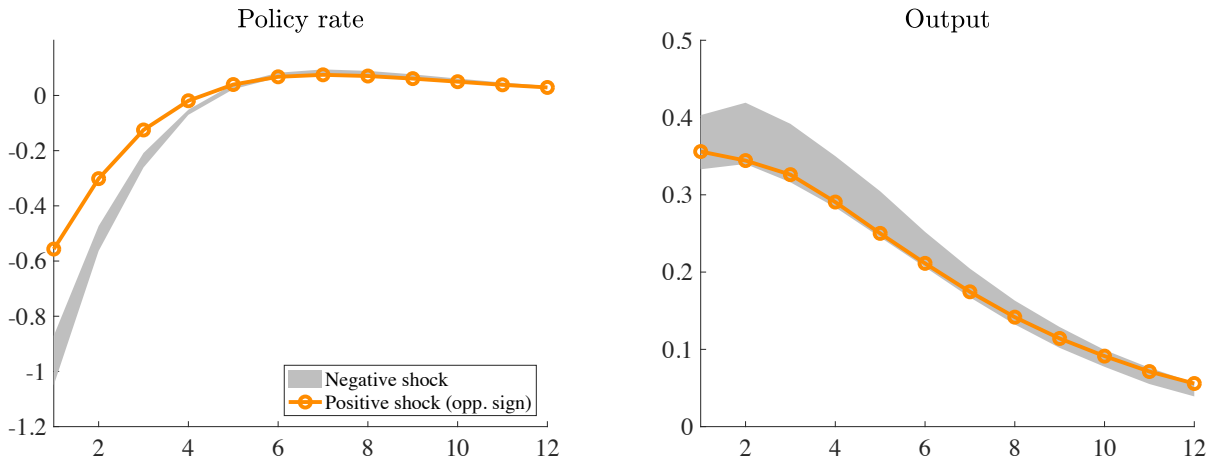
Note: Horizons in quarters. Monetary policy pass-through is measured as the ratio of the cumulated sum of the absolute value of the impulse responses of bank lending rates to the cumulated sum of the absolute value of the impulse responses of the policy rate: $\sum_{t=0}^{20} |\tilde{r}_t^{bs}(\pm \varepsilon_0^r)| / \sum_{t=0}^{20} |\tilde{r}_t(\pm \varepsilon_0^r)|$.

Figure 9 represents the pass-through after a positive (dotted orange line) and a negative (black line) monetary policy shock. The presence of asymmetric adjustment costs induces incomplete pass-through, including in the long run, as there is no catch-up of the initial incompleteness. We see that the pass-through associated with a negative monetary policy shock is initially weak, approximately 0.5 for both business and mortgage lending rates, and converges to 0.8, which therefore represents a considerable loss in the transmission of monetary policy. The pass-through is less limited in the case of a positive shock: it is initially higher than 0.8 and converges to one in the medium run.¹²

¹²However, note that the convergence to one does not mean that the pass-through is complete, because a complete pass-through would be equal to one plus a markup (1.11 in our case) in a monopolistic competition regime with flexible bank retail rates.

These findings demonstrate that monetary policy is less efficient in pushing the economy up than in pulling it down. From this perspective, downward BLR rigidity can contribute to explaining why loosening monetary policy in the case of downturn is like “*pushing on a string*”. In this respect, we now compute by how much the policy rate must be cut to have an impact on GDP that would be equivalent in amplitude to that of a policy rate increase. The answer is given by Figure 10. We find that a central bank would have to decrease its policy rate by 50% to 75% more (see the lefthand-side plot) to obtain an effect on GDP equal to that of a positive shock (see the righthand-side plot), in absolute value, over a two-year period. Policy would have to do more to achieve the type of adjustment implied by a state of the world without asymmetric banking frictions. It follows that neglecting downward interest rate rigidity within a macroeconomic model or in the general appreciation of the interest rate transmission mechanism may yield misguided monetary policy decisions.

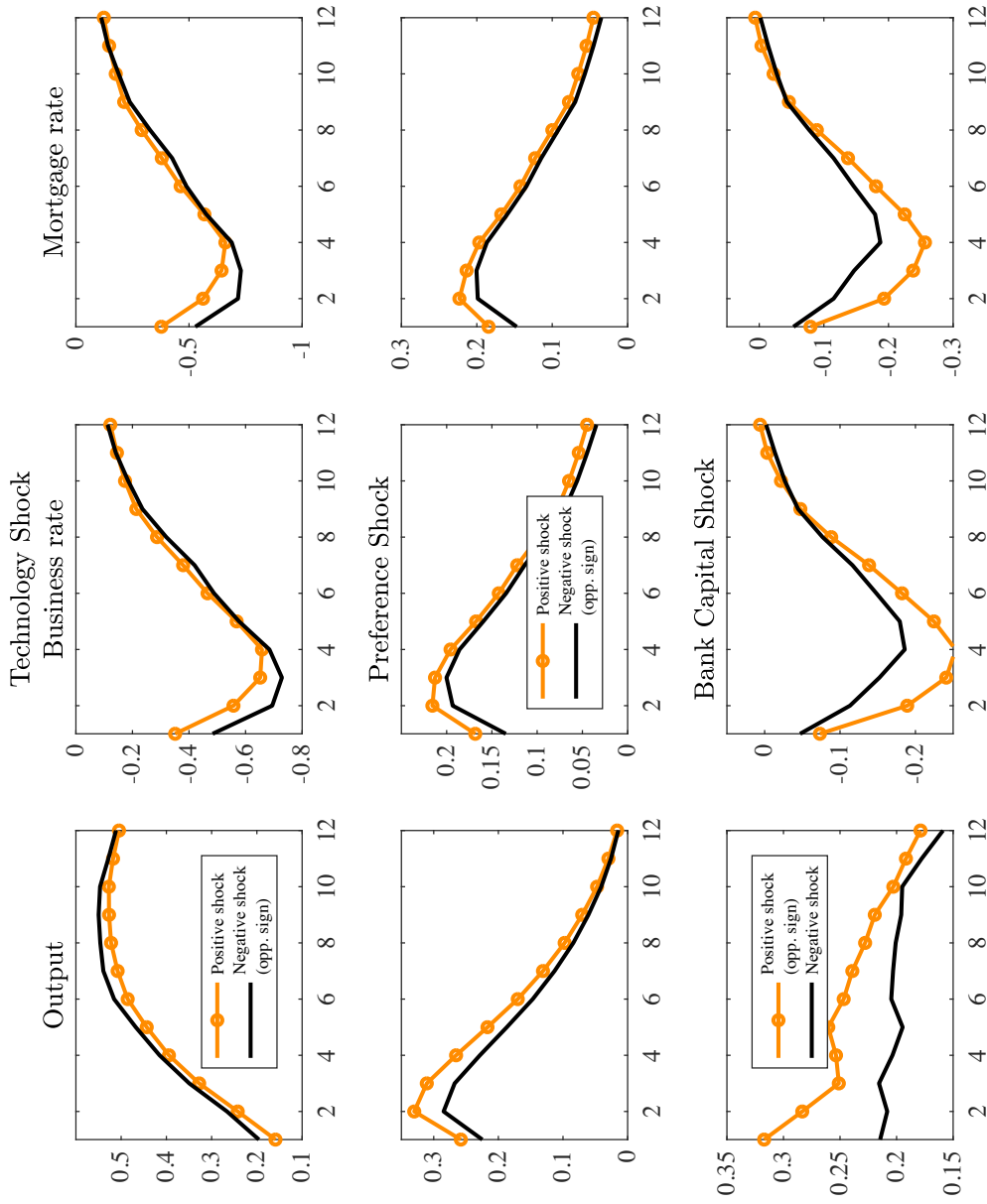
FIGURE 10. Negative monetary policy shocks for a symmetric GDP response



Note: Horizon in quarters. The gray area corresponds to different sizes of monetary policy shocks. The positive shock is shown in the opposite sign for comparison purposes.

5.2. Impulse responses to other shocks. As this paper primarily deals with monetary policy transmission, we have so far only considered the effects of monetary policy shocks. Nevertheless, downward lending rate rigidity has macroeconomic consequences regardless of the type of shock. As an example, Figure 11 shows the effects of positive and negative technology (ε_t^a), preference (ε_t^z) and bank capital (ε^{Kb}) shocks on output and bank lending rates. In each case, the response to a positive shock (orange dotted line) can be viewed as the symmetric benchmark.

FIGURE 11. Other Shocks



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

As usual, a positive technology shock (first row) 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 19% more in bad times over the four-year horizon than it increases in good times. A positive preference shock (second row) leads households and firms, through the increased demand they face, to demand more loans. Consequently, bank lending rates rise more than they decrease in response to a negative shock of similar amplitude. Hence, a negative demand shock has more impact on output than an equivalent positive shock, with a difference of approximately 15% on impact.

Finally, we consider a “positive” bank capital shock (last row), which means an exogenous decrease in bank capital (see eq. 8). 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 in lending rates. As a result, loans are actually reduced, as is output, while bank capital recovers.¹³ 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-third higher, at the impact, compared with the symmetric case (“negative shock”). This is an interesting result that may help to explain why banking crises are so harmful for the real sector. Furthermore, this implies that the “cleanup afterwards” strategy intended to dampen such banking crises has a rather limited impact, as implementing accommodative monetary policy is like pushing on a string.

Among all the shocks we have considered, monetary policy and bank capital shocks are those that imply the largest real deviations with respect to the symmetric case. This is because these two shocks have a direct impact on bank lending rates through the dynamics of the policy rate or the adjustment of bank balance sheets.

6. UNCONVENTIONAL MONETARY POLICY TRANSMISSION TO BANK LENDING RATES

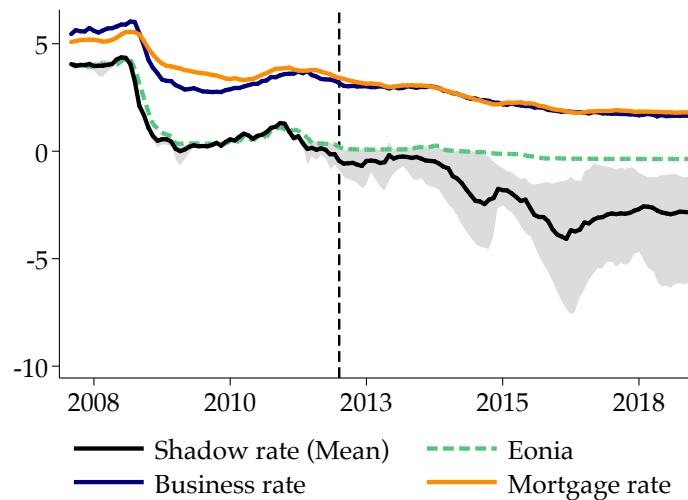
Thus far, we have shown that downward interest rate rigidity impedes the effectiveness of monetary policy in normal times, i.e., when the main instrument of a central bank is the policy rate, as soon as it has not reached its lower bound. However, in July 2012, the ECB decided to lower rates by 25 basis

¹³Not only does the deposit rate increase less than lending rates; deposits also decrease in the wake of this recessive shock.

points, bringing the deposit facility rate 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 interest rate also applies to average reserve holdings in excess of the minimum reserve requirements and to other deposits held with the Eurosystem. 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). Figure 12 shows that bank lending rates for nonfinancial companies and households continued to decline in concert with Eonia over the 2012-2018 period. This comovement seems to provide evidence of ongoing pass-through. However, the Eonia rate is poorly illustrative of monetary policy over this period. Indeed, several unconventional measures, such as forward guidance, liquidity injections or large-scale asset purchases, have been implemented at the same time (see [Hartmann and Smets, 2018](#), for a review).

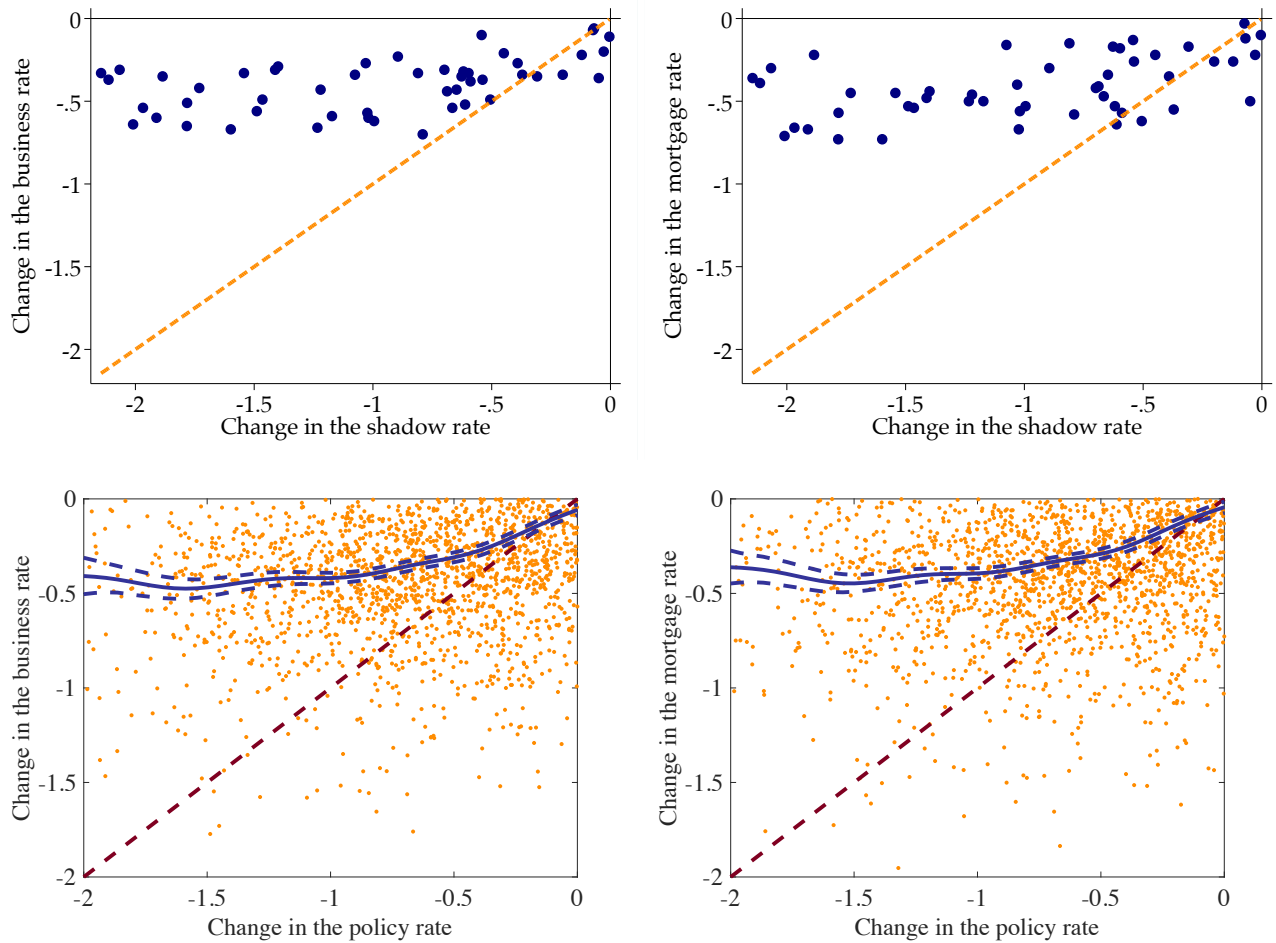
FIGURE 12. Bank lending rates, shadow rates and negative interest rate environment (percent)



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%.

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. The shadow rate coincides with the policy rate in normal times and is free to go into negative territory when the policy rate is stuck at its lower bound. [Wu and Xia \(2016\)](#), [Sims and Wu \(2019\)](#) and [Mouabbi and Sahuc \(2019\)](#) incorporate shadow

FIGURE 13. Observed and simulated scatter plots of the changes in the shadow and bank lending rates over 2012-2018 (percent)



Note: The first row reports the observed scatter plots. The second row reports the scatter plots for the simulated data, based on 5000 simulations of the asymmetric model with $\kappa_{bs} = 50$ and $\psi_{bs} = 1700$. The solid blue line represents the nonparametric regression, and the thick dashed lines delineate the 90% confidence interval obtained by standard bootstrap techniques.

rates into vector autoregressive or DSGE models to analyze the effects of unconventional monetary policies.

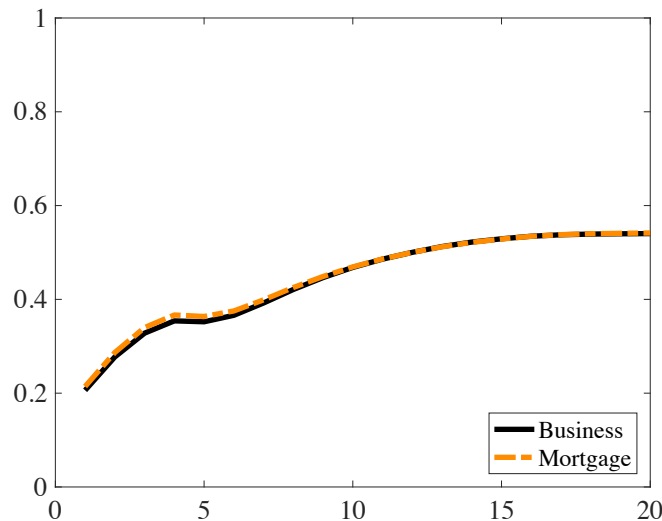
To capture the uncertainty surrounding its measurement, we consider a set of four shadow rates proposed by [Krippner \(2015\)](#), [Wu and Xia \(2016\)](#), [Kortela \(2016\)](#) and [Lemke and Vladu \(2017\)](#). The gray area in [Figure 12](#) reports the range of the corresponding shadow rates, while the black line is the mean value of this set of shadow rates. Looking at shadow rates rather than the Eonia rate offers a different picture. 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 the first row of plots in [Figure 13](#), which shows that BLRs reacted

slightly downward as the shadow rate was decreasing, but with a constant amplitude (approximately 40 bp), irrespective of the size of the shadow rate changes.¹⁴

This disruption of the pass-through as the shadow rate decreases may have at least two explanations. First, BLRs are likely to be positively bounded 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 above a given threshold for profitability reasons. Indeed, bank deposit rates are highly rigid (see Appendix B), and they tend to be bounded close to zero, especially for household deposits.¹⁵ 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 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.¹⁶

:medskip

FIGURE 14. Monetary policy pass-through at the effective lower bound



Note: Horizons in quarters. Monetary policy pass-through is measured as the ratio of the cumulated sum of the absolute value of the impulse responses of bank lending rates to the cumulated sum of the absolute value of the impulse responses of the policy rate: $\frac{\sum_{t=0}^{20} |\bar{r}_t^{bs}(\pm \varepsilon_0^r)|}{\sum_{t=0}^{20} |\bar{r}_t(\pm \varepsilon_0^r)|}$.

¹⁴Note 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).

¹⁵In our model, this suggests that $\kappa_d \rightarrow \infty$ as the deposit rate tends to zero.

¹⁶Amzallag 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.

These two explanations suggest that κ_{bs} and ψ_{bs} tend to be very high as BLRs tend to 0. From this point of view, the asymmetry of the monetary policy pass-through on BLRs is not only size-driven but also level-driven. In this regard, the second row of plots in Figure 13 shows that the BLR–shadow rate nexus observed over 2012-2018 in the euro area can be replicated provided that the parameters governing the degrees of rigidity and asymmetry of the BLRs are considerably increased (i.e., $\kappa_{bs} = 50$ and $\psi_{bs} = 1700$) compared to their levels in the benchmark calibration. Finally, according to Figure 14, such degrees of rigidity and asymmetry considerably disrupt the pass-through of monetary policy decreases. The pass-through is reduced to 0.2 in the very short term and converges to 0.55 in the long term, compared to the [0.5-0.8] range found with the baseline calibration (see Figure 9).

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 due to frictions that are intrinsically related to banks’ business model: (i) their source of profits (e.g., fees and commissions charged for the provision of financial services and trading) is diversified; (ii) the counterparts of their transactions are much more diverse; and (iii) they are involved in a number of activities, apart from deposits and lending, such as securitization and hedging through derivatives. Given the range of the aforementioned activities, there is probably a lower bound on lending rates that reduces the effectiveness of monetary policy.

7. CONCLUDING REMARKS

In this paper, we show that downward interest rigidity has important macroeconomic consequences and 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 initial response of GDP to a negative monetary policy shock is 25% lower than its response to a positive shock of similar amplitude. This implies that a central bank would have to decrease its policy rate by 50% to 75% more to obtain a symmetric medium-run impact on GDP. We also show that these findings are exacerbated when policy rates are stuck at their effective lower bound, due to frictions that are intrinsically related to banks’ business model.

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, e.g., with respect to the degree of competition of the banking sector. 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. Hence, by loosening capital requirements in times of economic downturn, countercyclical capital requirements may be viewed as a solution to facilitate the transmission of monetary policy in such a context. However, the countercyclical capital buffer introduced by Basel III cannot be negative. This implies that macroprudential authorities should genuinely encourage banks to build up a capital buffer in times of economic growth to have sufficient macroprudential policy space, i.e., to allow a meaningful capital buffer release should a downturn materialize.¹⁷ This could compensate for the failure of monetary policy in lowering lending rates in the ELB context. Nevertheless, a loosening of capital requirements may conflict with the objective of financial stability, as low interest rates may encourage excessive risk-taking.

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¹⁷This is a strategy advocated by the European Central Bank, among others. See, e.g., [Darracq Pariès et al. \(2019\)](#).

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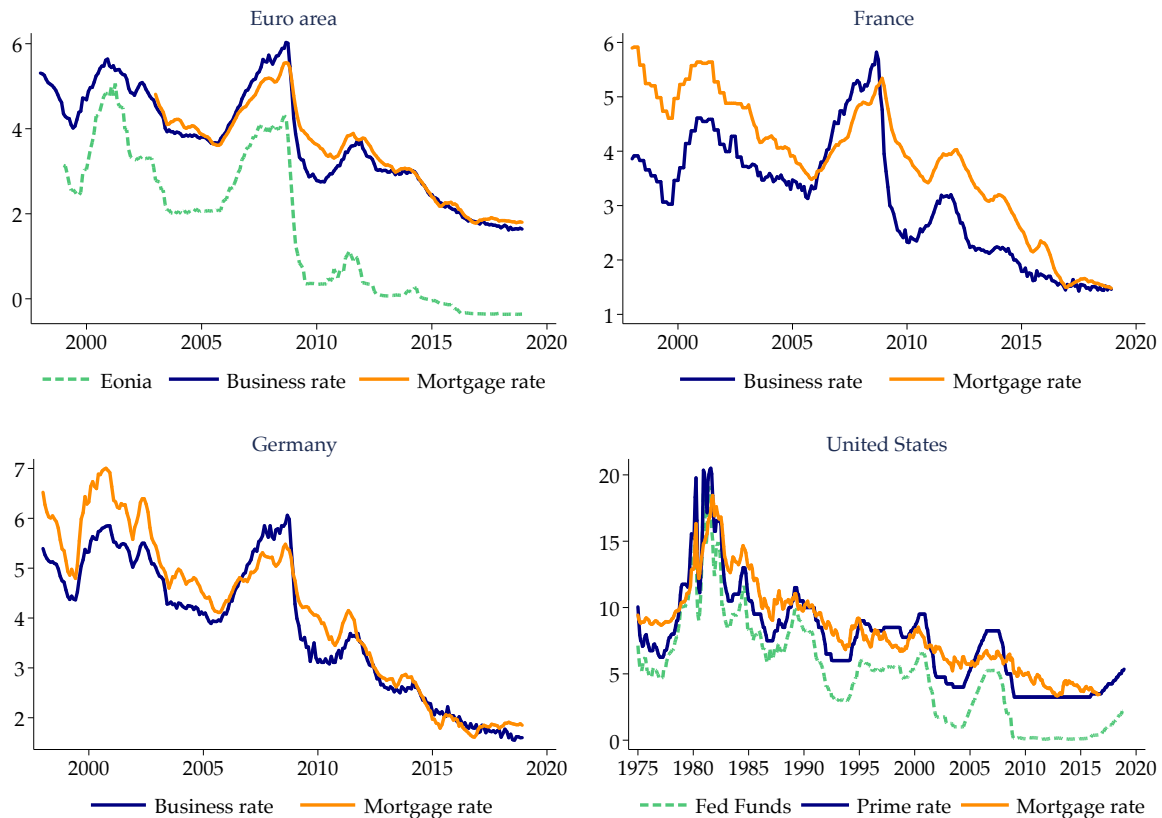
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APPENDIX A. DATA SOURCES

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.

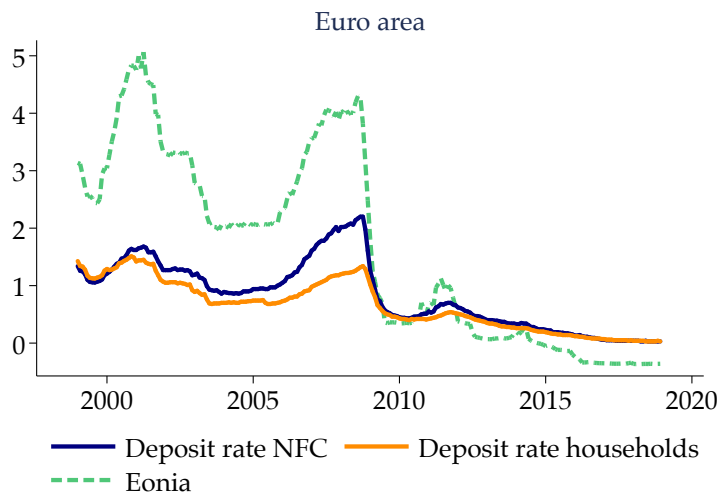
FIGURE A1. Policy rate and BLRs in the EA, France, Germany and the United States (percent)



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. The skewness of the year-on-year change in the deposit rate

	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).

APPENDIX C. ADDITIONAL EMPIRICAL EVIDENCE

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

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

Note: 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 of no skewness are in square brackets.

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

	France	Germany	United States
$\Delta BLR_{t-1} \leq \zeta$	0.299* (0.104)	0.867* (0.210)	0.604* (0.160)
$\Delta BLR_{t-1} > \zeta$	-0.003 (0.081)	0.121 (0.109)	0.333 (0.252)
Threshold ζ	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.

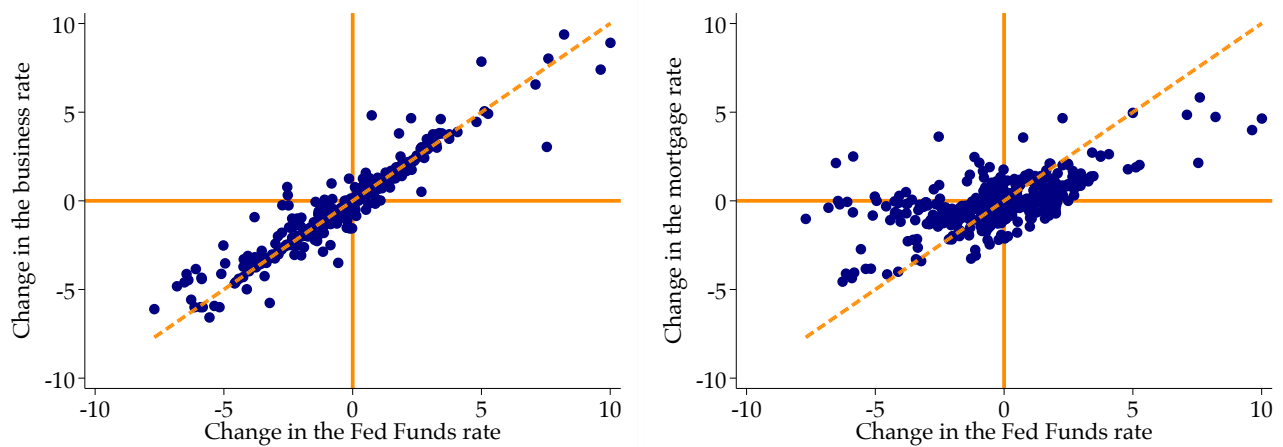
APPENDIX D. ADDITIONAL ELEMENTS ON BANK LENDING RATE STATISTICS IN THE UNITED STATES

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

	1975 - 2008	1975 - 2018
Business rate	0.297 [0.01]	0.258 [0.01]
Mortgage rate	0.366 [0.00]	0.470 [0.00]
Fed funds rate	0.172 [0.15]	0.098 [0.35]
Δ Business rate $-\Delta$ fed funds rate	0.518 [0.00]	0.673 [0.00]
Δ Mortgage rate $-\Delta$ fed funds rate	0.993 [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 i th household are given by:

$$E_0 \sum_{t=0}^{\infty} \beta_{\zeta}^t \left[(1 - a^{\zeta}) \varepsilon_t^z \log (c_t^{\zeta}(i) - a^{\zeta} c_{t-1}^{\zeta}) + \varepsilon_t^h \log h_t^{\zeta}(i) - \frac{l_t^{\zeta}(i)^{1+\phi}}{1+\phi} \right], \text{ for } \zeta \in \{P, I\} \quad (\text{E1})$$

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

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

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

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

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:

$$(1 + r_t^{bH}) b_t^I(i) \leq \varepsilon_t^{mI} E_t \left[q_{t+1}^h h_{t+1}^I(i) \pi_{t+1} \right] \quad (\text{E4})$$

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:

$$E_0 \sum_{t=0}^{\infty} \beta_E^t \log (c_t^E(i) - a^E c_{t-1}^E) \quad (\text{E5})$$

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:

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

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

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

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

$$(1 + r_t^{bE}) b_t^E(i) \leq \varepsilon_t^{mE} E_t \left((1 - \delta) q_{t+1}^k \pi_{t+1} k_t^E(i) \right) \quad (\text{E8})$$

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:

$$E_0 \sum_{t=0}^{\infty} \beta_\zeta^t \left\{ \Lambda_t^\zeta(i, m) \left[\frac{W_t^\zeta(m)}{P_t} l_t^\zeta(i, m) - \frac{\kappa_w}{2} \left(\frac{W_t^\zeta(m)}{W_{t-1}^\zeta(m)} - \pi_{t-1}^{\iota_w} \pi^{1-\iota_w} \right)^2 \frac{W_t^\zeta(m)}{P_t} \right] - \frac{l_t^\zeta(i, m)^{1+\phi}}{1+\phi} \right\}, \quad (\text{E9})$$

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

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

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:

$$\max_{\{k_t(i), i_t(i)\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^e \left(q_t^k [k_t(i) - (1 - \delta)k_{t-1}(i)] - i_t(i) \right) \quad (\text{E11})$$

subject to

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

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

$$\max_{\{P_t(\nu)\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[\left(P_t(\nu) - P_t^W \right) y_t(\nu) - \frac{\kappa_P}{2} \left(\frac{P_t(\nu)}{P_{t-1}(\nu)} - \pi_{t-1}^{\iota_p} \pi^{1-\iota_p} \right)^2 P_t y_t \right] \quad (\text{E13})$$

subject to the demand derived from consumers' maximization

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

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:

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

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

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

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

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

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

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

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

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

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 $\lambda_{t+j}^x, \forall x = \{I, P, E\}$ and $j = \{0, 1\}$, s_t^I and s_t^E are Lagrange multipliers. \mathcal{P}_t^I represents the profits of retailers in t . A variable without a temporal subscript designates its steady-state value.

Impatient Households

$$c_t^I + q_t^h (h_t^I - h_{t-1}^I) + (1 + r_{t-1}^{bH}) b_{t-1}^I / \pi_t = w_t^I l_t^I + b_t^I + \tau_t^I \quad (\text{F1})$$

$$(1 + r_t^{bH}) b_t^I \leq \varepsilon_t^{mI} E_t [q_{t+1}^h h_t^I \pi_{t+1}] \quad (\text{F2})$$

$$\frac{(1 - a^I) \varepsilon_t^z}{c_t^I - a^I c_{t-1}^I} = \lambda_t^I \quad (\text{F3})$$

$$\lambda_t^I q_t^h = \frac{\varepsilon_t^h}{h_t^I} + \beta_I E_t \left[(\lambda_{t+1}^I q_{t+1}^h + s_t^I \varepsilon_t^{mI} q_{t+1}^h \pi_{t+1}) \right] \quad (\text{F4})$$

$$\lambda_t^I = \beta_I E_t \left[\lambda_{t+1}^I \frac{(1 + r_t^{bh})}{\pi_{t+1}} \right] + s_t^I (1 + r_t^{bh}) \quad (\text{F5})$$

$$\begin{aligned} \kappa_w (\pi_t^{wI} - \pi_{t-1}^{tw} \pi^{1-t_w}) \pi_t^{wI} &= \beta_I E_t \left[\frac{\lambda_{t+1}^I}{\lambda_t^I} \kappa_w (\pi_{t+1}^{wI} - \pi_t^{tw} \pi^{1-t_w}) \frac{(\pi_{t+1}^{wI})^2}{\pi_{t+1}} \right] \\ &+ (1 - \varepsilon_t^l) l_t^I + \frac{\varepsilon_t^l (l_t^I)^{1+\phi}}{w_t^{wI} \lambda_t^I} \end{aligned} \quad (\text{F6})$$

$$\pi_t^{wI} = \frac{w_t^{wI}}{w_{t-1}^{wI}} \pi_t \quad (\text{F7})$$

Patient Households

$$c_t^P + q_t^h (h_t^P - h_{t-1}^P) + d_t^P = w_t^P l_t^P + (1 + r_{t-1}^d) d_{t-1}^P / \pi_t + t_t^P \quad (\text{F8})$$

$$\frac{(1 - a^P) \varepsilon_t^z}{c_t^P - a^P c_{t-1}^P} = \lambda_t^P \quad (\text{F9})$$

$$\lambda_t^P q_t^h = \frac{\varepsilon_t^h}{h_t^P} + \beta_P E_t (\lambda_{t+1}^P q_{t+1}^h) \quad (\text{F10})$$

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

$$\begin{aligned} \kappa_w \left(\pi_t^{wP} - \pi_{t-1}^{lw} \pi^{1-lw} \right) \pi_t^{wP} &= \beta_P \mathbf{E}_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \kappa_w \left(\pi_{t+1}^{wP} - \pi_{t+1}^{lw} \pi^{1-lw} \right) \frac{(\pi_{t+1}^{wP})^2}{\pi_{t+1}} \right] \\ &+ \left(1 - \varepsilon_t^l \right) l_t^P + \frac{\varepsilon_t^l (l_t^P)^{1+\phi}}{w_t^{wP} \lambda_t^P} \end{aligned} \quad (\text{F12})$$

$$\pi_t^{wP} = \frac{w_t^{wP}}{w_{t-1}^{wP}} \pi_t \quad (\text{F13})$$

Entrepreneurs

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

$$\vartheta(u_t) = \xi_1 (u_t - 1) + \frac{\xi_2}{2} (u_t - 1)^2 \quad (\text{F15})$$

$$r_t^k = \xi_1 + \xi_2 (u_t - 1) \quad (\text{F16})$$

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

$$\frac{1 - a^E}{c_t^E - a^E c_{t-1}^E} = \lambda_t^E \quad (\text{F18})$$

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

$$\begin{aligned} \lambda_t^E q_t^k &= \beta_E \mathbf{E}_t \left\{ \lambda_{t+1}^E \left[r_{t+1}^k u_{t+1} + q_{t+1}^k (1 - \delta) - \left(\xi_1 (u_{t+1} - 1) + \frac{\xi_2}{2} (u_{t+1} - 1)^2 \right) \right] \right\} \\ &+ \mathbf{E}_t \left[s_{t+1}^E \varepsilon_{t+1}^{mE} q_{t+1}^k \pi_{t+1} (1 - \delta) \right] \end{aligned} \quad (\text{F20})$$

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

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

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

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

Capital Producers

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

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

Final Goods Producers (Retailers)

$$P_t^r = y_t \left(1 - \frac{1}{x_t} \right) - \frac{\kappa_P}{2} \left(\pi_t - \pi_{t-1}^{lp} \pi^{1-lp} \right)^2 \quad (\text{F27})$$

$$0 = 1 - \varepsilon_t^y + \frac{\varepsilon_t^y}{x_t} - \kappa_P \left(\pi_t - \pi_{t-1}^{lp} \pi^{1-lp} \right) \pi_t \\ + \beta_P E_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \kappa_P \left(\pi_{t+1} - \pi_t^{lp} \pi^{1-lp} \right) \pi_{t+1} \frac{y_{t+1}}{y_t} \right] \quad (\text{F28})$$

Banks' Retail Units

$$0 = 1 - \varepsilon_t^{bE} + \varepsilon_t^{bE} \frac{R_t^b}{r_t^{bE}} - \left(\kappa_{bE} \left(\frac{r_t^{bE}}{r_{t-1}^{bE}} - 1 \right) + \frac{1}{\psi_{bE}} \left\{ 1 - \exp \left[-\psi_{bE} \left(\frac{r_t^{bE}}{r_{t-1}^{bE}} - 1 \right) \right] \right\} \right) \frac{r_t^{bE}}{r_{t-1}^{bE}} \\ + \beta_P E_t \left\{ \left(\kappa_{bE} \left(\frac{r_{t+1}^{bE}}{r_t^{bE}} - 1 \right) + \frac{1}{\psi_{bE}} \left\{ 1 - \exp \left[-\psi_{bE} \left(\frac{r_{t+1}^{bE}}{r_t^{bE}} - 1 \right) \right] \right\} \right) \frac{\lambda_{t+1}^P}{\lambda_t^P} \left(\frac{r_{t+1}^{bE}}{r_t^{bE}} \right)^2 \frac{b_{t+1}^E}{b_t^E} \right\} \quad (\text{F29})$$

$$0 = 1 - \varepsilon_t^{bH} + \varepsilon_t^{bH} \frac{R_t^b}{r_t^{bH}} - \left(\kappa_{bH} \left(\frac{r_t^{bH}}{r_{t-1}^{bH}} - 1 \right) + \frac{1}{\psi_{bH}} \left\{ 1 - \exp \left[-\psi_{bH} \left(\frac{r_t^{bH}}{r_{t-1}^{bH}} - 1 \right) \right] \right\} \right) \frac{r_t^{bH}}{r_{t-1}^{bH}} \\ + \beta_P E_t \left\{ \left(\kappa_{bH} \left(\frac{r_{t+1}^{bH}}{r_t^{bH}} - 1 \right) + \frac{1}{\psi_{bH}} \left\{ 1 - \exp \left[-\psi_{bH} \left(\frac{r_{t+1}^{bH}}{r_t^{bH}} - 1 \right) \right] \right\} \right) \frac{\lambda_{t+1}^P}{\lambda_t^P} \left(\frac{r_{t+1}^{bH}}{r_t^{bH}} \right)^2 \frac{b_{t+1}^H}{b_t^H} \right\} \quad (\text{F30})$$

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

Banks' Wholesale Units

$$B_t \equiv b_t^H + b_t^E = D_t + K_t^b \quad (\text{F32})$$

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

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

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

Monetary Policy

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

Market Clearing and Identities

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

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

Exogenous Shocks

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

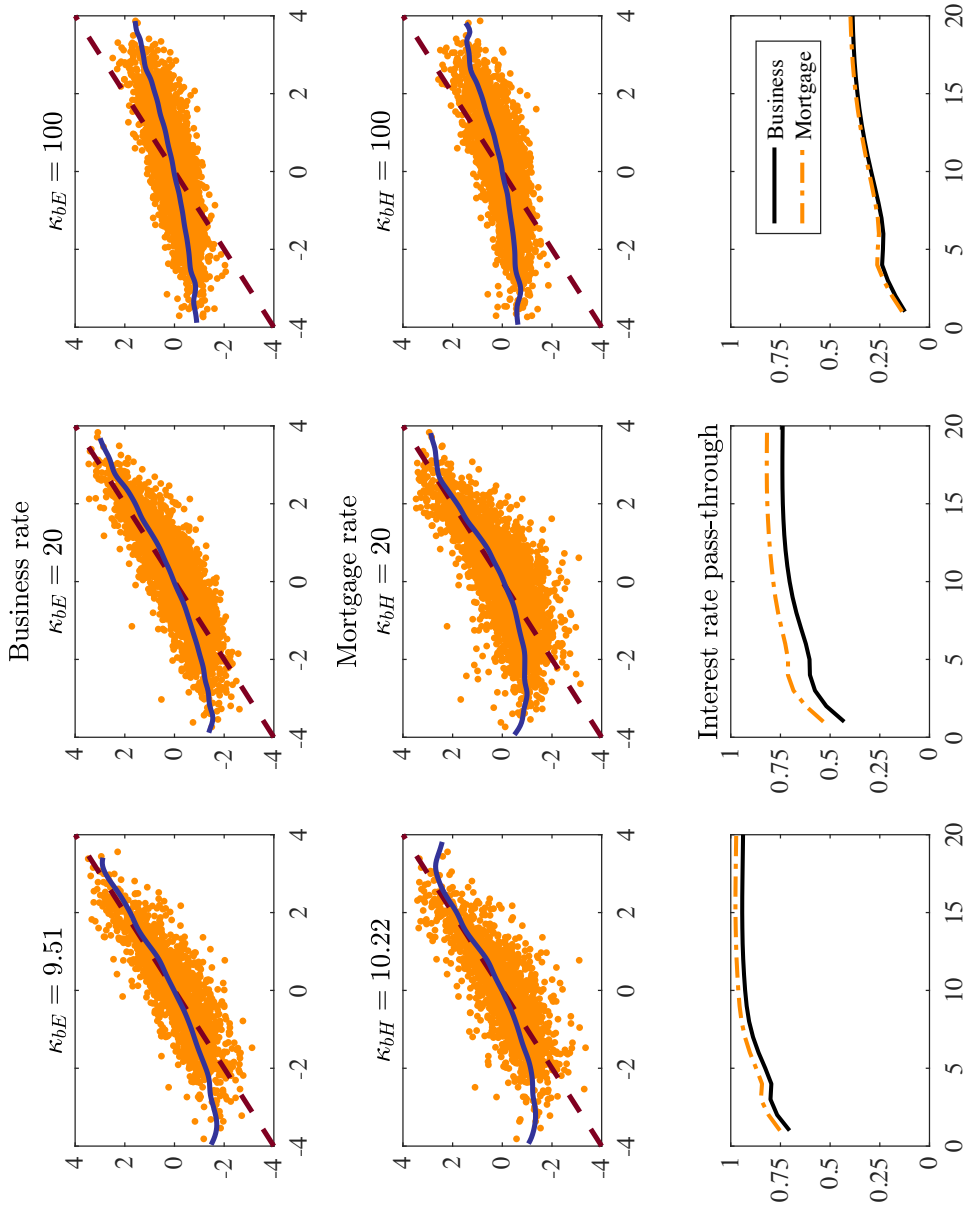
with $\vartheta = \{a, z, h, l, qk, y, Kb, d, bH, bE, mI, mE\}$.

APPENDIX G. DETAILS ON THE CALIBRATION OF THE MODEL

TABLE G1. Calibrated parameters

Parameter	Description	Value
κ_{bE}	Cost of adjusting BLR to entrepreneurs	6.0
κ_{bH}	Cost of adjusting BLR to households	6.0
ψ_{bE}	Asymmetric parameter in BLR adjustment costs - entrepreneurs	230
ψ_{bH}	Asymmetric parameter in BLR adjustment costs - households	260
κ_d	Cost of adjusting deposit rate	3.50
$\varepsilon^{bE}/(\varepsilon^{bE} - 1)$	Steady-state markup on BLR to entrepreneurs	1.11
$\varepsilon^{bH}/(\varepsilon^{bH} - 1)$	Steady-state markup on BLR to households	1.11
$\varepsilon^d/(\varepsilon^d - 1)$	Steady-state markdown on deposit rate	0.593
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	0.06
β_P	Patient households' discount factor	0.9943
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	0.05
a^P, a^I, a^E	Degree of habit formation in consumption	0.856
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	0.0377
ξ_2	Parameter of adjustment cost for capacity utilization	0.0038
ε^{mE}	Steady-state LTV ratio for entrepreneurs	0.9
κ_w	Cost for adjusting nominal wages	99.89
ι_w	Indexation of nominal wages to past inflation	0.276
$\varepsilon^l/(\varepsilon^l - 1)$	Steady-state markup in the labor market	5.0
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	6.0
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
$\rho_z ; \sigma_z$	Persistence and std deviation - preference shock	0.39 ; 0.027
$\rho_h ; \sigma_h$	Persistence and std deviation - housing preference shock	0.92 ; 0.071
$\rho_{mE} ; \sigma_{mE}$	Persistence and std deviation - firms' LTV shock	0.89 ; 0.007
$\rho_{mI} ; \sigma_{mI}$	Persistence and std deviation - households' LTV shock	0.93 ; 0.003
$\rho_d ; \sigma_d$	Persistence and std deviation - deposit markdown shock	0.84 ; 0.032
$\rho_{bE} ; \sigma_{bE}$	Persistence and std deviation - BLR markup shock (entrepreneurs)	0.83 ; 0.063
$\rho_{bH} ; \sigma_{bH}$	Persistence and std deviation - BLR markup shock (households)	0.82 ; 0.066
$\rho_a ; \sigma_a$	Persistence and std deviation - technology shock	0.94 ; 0.006
$\rho_{qk} ; \sigma_{qk}$	Persistence and std deviation - investment efficiency shock	0.55 ; 0.019
$\rho_y ; \sigma_y$	Persistence and std deviation - price markup shock	0.30 ; 0.598
$\rho_w ; \sigma_w$	Persistence and std deviation - wage markup shock	0.64 ; 0.561
$\rho_{Kb} ; \sigma_{Kb}$	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 and interest rate pass-through



Note: The scatter plots are based on 4000 simulations of the asymmetric model for different values of κ_{bE} . The solid blue line represents the nonparametric regression. The last line plots the monetary policy pass-through, measured as the ratio of the cumulated sum of the absolute value of the impulse responses of bank lending rates to the cumulated sum of the absolute value of the impulse responses of the policy rate: $\sum_{t=0}^{20} |r_t^{bs}(\pm \varepsilon_0^r)| / \sum_{t=0}^{20} |\tilde{r}_t(\pm \varepsilon_0^r)|$. Horizons in quarters.