Interest rate pass-through and interbank rate volatility shocks: a DSGE perspective

Vincent Bouvatier*     Mohammed Chahad†

February 19, 2014

Abstract

In this paper, we use a New Keynesian framework to investigate the interest rate pass-through in the euro area. More precisely, we analyze the effects of an interbank rate volatility shock on the economy and more particularly on the interest rate pass-through. We show that an interbank rate volatility shock leads to an upward pressure on retail interest rates. The transmission of an expansionary monetary policy to bank interest rates and more generally to the economy can therefore be noticeably reduced by the rise in the interbank rate uncertainty.

JEL Classification: E43, E52, G21.

Keywords: Interest rate pass-trough, volatility shock, DSGE.

*EconomiX-CNRS, University of Paris Ouest, France. E-mail: vbouvatier@u-paris10.fr
†EconomiX-CNRS, University of Paris Ouest and Banque de France. E-mail: mohammed.chahad@gmail.com
1 Introduction

Would there be something more to say about the interest rate pass-through? Indeed, the pass-through from the monetary policy rate to retail interest rates has been widely investigated in the empirical literature. Results emphasize short-term stickiness in bank interest rates as well as differences across countries and over time. The understanding of these differences matters particularly for central banks since they need to assess the transmission mechanisms of monetary policy shocks. Furthermore, the empirical literature on the interest rate pass-through does not focus on a single measure of the stickiness in retail interest rates but provides rather a wide range of results. First, numerous retail interest rates are considered both on loans and on deposits.\footnote{See for example de Bondt (2005) which provides a literature review and reports empirical estimates of the interest rate pass-through in euro area countries for 6 market segments: short-term loans to firms, long-term loans to firms, consumer credit, mortgages, savings deposits and time deposits.} Second, the pass-through to retail interest rates can be measured against a money market rate or against a market rate of comparable maturity. The former proxies the monetary policy rate and then focuses on monetary policy transmission. The latter proxies bank’s cost of funds and then highlights the role of competition and market structure (Sander and Kleimeier (2004)). Third, empirical studies can estimate both short-term and long-term interest rate pass-through. As a result, all these measures provide complementary insights on banks’ price-setting behavior.

The theoretical literature on the interest rate pass-through is rather scarce. It is however essential to understand the main determinants and implications of the sluggishness of retail interest rates. For example, structural approaches, based on the New Keynesian framework, show that the stickiness of retail interest rates and an incomplete interest rate pass-through weaken the monetary policy efficiency (Kwapil and Scharler (2010), Darraaq Pariès et al. (2011)), mitigate the strength of the cost channel of monetary policy (Hülsewig et al. (2009)) and reduce social welfare (Kobayashi (2008)). Our paper falls within this category of studies, we also adopt a New Keynesian framework mainly drawn from Iacoviello (2005) and Gerali et al. (2010) and we provide in particular an explanation of the slowdown in the interest rate pass-through identified during the 2007-2008 financial crisis (IMF (2008), Čihák et al. (2009), Aristei and Gallo (2012), Hristov et al. (2012)).

The paper has three main contributions. First, we analyze the impact of an interbank rate volatility shock on the interest rate pass-through. Second, we provide a complementary explanation of the stagflationary effect generated by volatility shocks to the one presented by Fernández-Villaverde et al. (2012). Third, we evaluate how the central bank can mitigate the impact of an interbank rate volatility shock on retail interest rates. The main finding is that the transmission of a monetary policy easing to retail interest rates is impeded when an interbank rate volatility shock occurs at the same time as the decrease in the policy rate. In addition, we also show that, conversely, the impact of a restrictive monetary policy can be amplified in times of high interbank volatility corresponding to times where the pass-through is likely to exceed the unit value. Finally, we find that a central bank putting more weight on the GDP stabilization objective in the monetary policy rule and increasing the policy rate smoothing can reduce the consequences of the interbank rate volatility shock.

The rest of the paper is organized as follows. Section 2 is devoted to the literature review and
the presentation of stylized facts. Sections 3 and 4 present respectively the theoretical model and its calibration. Impulse response functions are analyzed in Section 5. The transmission of the monetary policy in time of interbank uncertainty is analyzed in section 6. Section 7 concludes the article.

2 Literature review and stylized fact

2.1 Literature review on interest rate pass-through

The euro area creation gave rise to a large volume of empirical research on the interest rate pass-through for two main reasons. First, the euro area merges heterogeneous banking sectors. The single monetary policy can then affect differently national banking sectors, which is a major concern for the European Central Bank (ECB). Second, the financial integration between members countries increased since the euro area creation until the Great Financial Crisis. This has the potential to increase, which can modify the monetary policy transmission process over time. Based on country level data, Sander and Kleimeier (2004) find that the pass-through from the monetary policy rate to lending rates increased and became more homogeneous across euro area countries. Angeloni and Ehrmann (2003), Vajanne (2007) and Nakajima and Teranishi (2009) reach similar conclusions. The remaining heterogeneity can be explained by differences in macroeconomic performances and in banking sector characteristics as the degree of competition (Kok Sørensen and Werner (2006), Kleimeier and Sander (2006), Gropp et al. (2007) and van Leuvensteijn et al. (2008)).

Empirical studies suggest further that the interest rate pass-through is lower to deposit rates than to lending rates and that the long-run pass-through is usually incomplete for most retail interest rates. Considering euro area as a whole, de Bondt (2005) investigates both the pass-through from the monetary policy rate to market rates (i.e. bank's cost of fund) and the pass-through from market rates to retail bank interest rates. He finds that short-run pass-throughs are around 50% while long-run pass-throughs are nearly complete for market rates and lending rates.

The empirical literature is however not only devoted to the euro area. Differences in the strength and in the speed of the transmission process across many countries have already been investigated. For example, Panagopoulos et al. (2010) make comparison between the US, UK, Canada and Eurozone; Sander and Kleimeier (2006) and Égert et al. (2007) focus on transition economies in Central and Eastern Europe; Wang (2010b) on Asian countries; and Gigineishvili (2011) adopts a wider approach considering seventy countries.

The stability of the relationships between retail interest rates and the monetary policy rate has logically been questioned during and following the 2007-2008 financial crisis. In this regard, IMF (2008) underlines that financial intermediation changed over the last decade with a larger part of financial intermediation provided by "near-bank" financial institutions while short term financing became more important in banks' liabilities. IMF (2008) documents two main implications of these structural changes. First, tightening in credit market during the financial crisis occurred mainly by downward quantity adjustments rather than lending rates increases. Second, the pass-through of policy rates to short-term lending rates have been impeded by the
financial turmoil in the US, and to a lesser extent in the euro area. Čihák et al. (2009), Aristei and Gallo (2012) and Hristov et al. (2012) reach similar conclusions for the euro area and find that the pass-through to market rates has slowed down during the crisis. Empirical evidences from ECB (2009) are more in line with the stability of the pass-through and suggest that the linkages between retail interest rates and market rates in the euro area since mid-2007 do not differ markedly from past patterns.

Several theoretical studies investigate the reasons behind the slowdown in the interest rate pass-through identified during the 2007-2008 financial crisis. Based on simulations of a DSGE model, Hristov et al. (2012) put forward that an increase in the frictions characterizing the banking sector, as for example tighter collateral requirements, dampens the interest rate pass-through. Roelands (2013), in a partial equilibrium framework, shows that binding capital or liquidity constraints, more frequently observed during monetary policy easing, slow down the interest rate pass-through while Ritz (2012) shows that a rise in funding uncertainty dampens the interest rate pass-through from the monetary policy rate to market interest rates.

The last argument putting forward the role of money market uncertainty and its impact on retail rate has also been investigated in the literature, especially the empirical one since the theoretical literature has long relied on the assumption of homoscedastic stochastic process. Raunig and Scharler (2009) study the transmission of money market volatility to retail rates in 10 OECD countries. They find that the volatility of money market rates has a limited impact on the volatility of retail interest rates, except in the US. They conclude that banks smooth shocks and then contribute to macroeconomic stability. However, Raunig and Scharler (2009) use a simplistic approach to assess the retail interest rates volatility. In addition, the volatility transmission could be magnified during periods of financial crisis. Wang and Lee (2009) and Wang (2010b,a) paid a particular attention in modeling the retail interest rates volatility to estimate retail interest rate pass-through in 9 Asian countries and in the US. They do not address the issue of volatility transmission but they clearly identify volatility shocks in retail interest rates.

2.2 Identification of volatility shocks

Focusing on the euro area, we illustrate the presence of uncertainty (i.e. volatility shocks) in the money market interest rate and in the lending rates. We proceed in two step to model the fluctuations in interest rates in the spirit of Wang and Lee (2009). In the first step, we identify the long-run dynamics of the money market and of the lending rates with cointegration relations. In a second step, the short-run dynamics are assessed with an error correction specification including a multivariate GARCH process. Three variables are used in the model. We use the Eonia rate ($Eonia_t$) as the monetary policy rate, the 1-year Euribor rate ($Euribor_{1Y}^t$) as the money market rate and the short term lending rate to non-financial corporations ($r_{L1Y}^t$) as the retail rate. We consider the January 1997-April 2012 period and all the data come from the ECB databases. The Dickey and Fuller (1979), Elliott et al. (1996), Perron (1997) and

\footnote{The Euribor rates with shorter maturities have also been considered to represent the money market rate. We decided to retain the Euribor rate which exhibits the stronger cointegration relationship with the retail rate, based on the Phillips and Ouliaris (1990) cointegration tests. Similarly, alternative retail rates could have been considered but our empirical illustration does not seek to be exhaustive.}
Kwiatkowski et al. (1992) tests indicate that the 3 variables are non stationary in level and stationary in first difference.

First, we estimate the two following long-run relations to evaluate the pass-through from the policy rate to the money market rate and from the money market rate to the retail rate:

\[ \text{Euribor}_{1Y}^t = b_{10} + b_{11} \text{Eonia}_{1t} + \varepsilon_{1t} \]  \hspace{1cm} (1)

\[ r_{Lt}^L = b_{20} + b_{21} \text{Euribor}_{1Y}^t + \varepsilon_{2t} \]  \hspace{1cm} (2)

Equations (1) and (2) are estimated by Fully Modified Least Squares (FMOLS) and results are reported in Table 1. The Phillips and Ouliaris (1990) cointegration tests confirm that Equations (1) and (2) can be considered as long-run relations and \( \varepsilon_{1t} \) and \( \varepsilon_{2t} \) represent therefore long-run error terms. The pass-through from the policy rate to the money market rate (\( b_{11} \)) is 0.82 while the one from the money market rate to the retail rate (\( b_{21} \)) is 0.84. Both coefficients are significant at the 1% level and also significantly different from 1 at the 1% level, suggesting an incomplete pass-through in the long-run.\(^3\)

Second, we identify volatility shocks with the following short-run specification:

\[ \Delta \text{Euribor}_{1Y}^t = k_{10} + k_{11} \Delta \text{Euribor}_{1Y}^{t-1} + k_{12} \Delta \text{Eonia}_{1t-1} + k_{13} \hat{\varepsilon}_{1t-1} + u_{1t} \]  \hspace{1cm} (3)

\[ \Delta r_{L}^L = k_{20} + k_{21} \Delta r_{L}^{t-1} + k_{22} \Delta \text{Euribor}_{1Y}^{t-1} + k_{23} \hat{\varepsilon}_{2t-1} + u_{2t} \]  \hspace{1cm} (4)

with

\[ u_t = (u_{1t}, u_{2t})' - N(0, H_t) \]

where \( H_t \), corresponding to the variance-covariance matrix, is represented by a diagonal BEKK specification (Engle and Kroner (1995)).\(^4\) More precisely:

\[ H_t = C'C + A' u_{t-1} u_{t-1}' A + G' H_{t-1} G \]  \hspace{1cm} (5)

where \( C \) is a 2x2 triangular matrix of constants, \( A \) and \( G \) are 2x2 diagonal matrix. Matrix \( A \) measures the effects of shocks on the elements of \( H_t \) and matrix \( G \) introduces the volatility persistence. According to the diagonal parametrization, the variances depend on their own past squared residual and on their own past value while the covariance depend on the product of residuals and on its own past value.

The bivariate diagonal BEKK model, made up of equations (3), (4) and (5), is estimated by maximum likelihood. A multivariate normal distribution is used and the Bollerslev-Wooldridge standard errors are considered. The results are reported in Table 2. Regarding the mean equations, all the parameters (except the intercepts) are significant at the 1% or 5% levels. Money market rate and lending rate variations positively depend on their own past value, suggesting smooth adjustments. In addition money market rate variations depend on past

---

\(^3\)Note that a complete long-run pass-through from the policy rate to the money market rate is obtained if the 1-month or 3-month Euribor rates are used instead of the 1-year Euribor rate.

\(^4\)The BEKK specification ensure that the estimated covariance matrix will be positive semi-definite, which guarantee non-negative estimated variances. Furthermore, two alternative specifications have been considered for robustness check. First, we used a DCC-GARCH model (Engle (2002)). Second, we used a trivariate diagonal BEKK model; including a third equation to represent \( \Delta \text{Eonia}_t \) as an autoregressive process. Similar conclusions have been reached with these two alternative specifications.
variations in the policy rate while lending rate variations depend on past variations in the money market rate. Finally, short term fluctuations are characterized by an error correction mechanism. Variables $\hat{\varepsilon}_{1,t-1}$ and $\hat{\varepsilon}_{2,t-1}$ affect negatively respectively the money market and the lending rates.\(^5\) Concerning the variance-covariance equations, parameters from matrix $A$ and $G$ are significant at the 1% level suggesting respectively the presence of ARCH effects and volatility persistence. Figure 1 represents conditional standard deviations and correlation obtained from the BEKK model. The dynamics of the money market and lending rates have been affected by volatility shocks, particularly during the financial crisis. Before 2008, volatility in the lending rate was weaker and more stable than the one in the money market rate, suggesting that banks provide insurance against interest rates shocks (Raunig and Scharler (2009)). However, this behavior was challenged during the financial crisis and uncertainty increased both in the money market and in the lending rates. In addition, Figure 1 shows that conditional correlation in shocks increased during the financial crisis, reinforcing the fact that volatility shocks are not restricted to the money market. As a result, we conclude from the BEKK model that during a financial crisis, banks cannot absorb the increasing uncertainty in the money market rate. Retail interest rates are then also affected. To the best of our knowledge, consequences of these volatility shocks on the interest rate pass-through has never been investigated. The model developed in the following section allows to fill this research gap.

3 The model

Our benchmark model is mainly drawn from Iacoviello (2005) and Gerali et al. (2010). To focus on the main questions of our paper, we limit our description of the model to its standard features in order to fix notation.

3.1 Households

The economy is populated by two types of households. Both types of households consume, work and enjoy housing services. When the first type of households (called patient, indexed by $P$) are net lenders in the sense that, in each period, they can save some of their revenue in the form of banks deposits, the second type of households (called impatient, indexed by $I$) are net borrowers in our economy.

For each type of households $m = \{I, P\}$, an infinitely-lived representative household $i \in [0, 1]$ maximizes in each period its intertemporal utility function which is assumed to be of the form:

$$W_{t}^{m,i} = \mathbb{E}_{t} \left[ \sum_{j=0}^{\infty} \beta_{w,m}^{j} \left\{ \left( \frac{1 - \eta_{c}^{m} \left( \frac{C_{t+j}^{m,i} - \eta_{c}^{m} C_{t+j-1}^{m,i}}{1 - \eta_{c}^{m}} \right)^{1-\sigma_{c}^{m}} + \left( \frac{h_{t+k}^{m,i} (1-\sigma_{h}^{m}) - (N_{t+j}^{m,i} (1-\sigma_{n}^{m})}{1 - \sigma_{n}^{m}} \right) \right) \right\} \right]$$

where $C_{t}^{m,i}$, $h_{t}^{m,i}$ and $N_{t}^{m,i}$ represent respectively the household $m$’s consumption, housing demand and labor, when the parameters $\sigma_{c}^{m}$, $\sigma_{h}^{m}$ and $\sigma_{n}^{m}$ are the corresponding inter-temporal elasticity of substitution. $\eta_{c}^{m}$ measures the degree of external habit formation in consumption.

\(^5\)Additional exogenous variables could have been introduced, as variations in long-term interest rate for example, but we prefer a parsimonious specification in this empirical illustration.
Each period, the households maximize their utility function with respect to a budget constraint. For patient households, the budget constraint is written (in real terms) as:

$$\begin{align*}
C_t^{P,i} + D_t^{P,i} + q_t^h (h_t^{P,i} - h_{t-1}^{P,i}) = \frac{W_t^{P,i}}{P_t} - N_t^{P,i} + \frac{(1 + R_{t-1}^D)D_{t-1}^{P,i}}{\pi_t} + \mathcal{G}_t^{P,i} + \mathcal{J}_t^{P,i}
\end{align*}$$

(6)

Their resources are composed of wage earnings \(W_t^{P,i}/P_t\), gross interest income on last period deposits \(\frac{1 + R_{t-1}^D}{\pi_t}D_{t-1}^{w,h}\) as well as some lump-sum transfers \(\mathcal{J}_t^{P,i}\) and dividends \(\mathcal{G}_t^{w,h}\) from the different types of firms that all belong to them. Their flow of expenses includes, in addition of their current consumption \(C_t\) and the accumulation of housing \(h_t^{P,i}\), the amount of revenue they decide to save in the current period \(D_t^{P,i}\).

For impatient households, the budget constraint is written (in real terms) as:

$$\begin{align*}
C_t^{I,i} + \frac{(1 + R_{t-1}^L) L_{t-1}^{I,i}}{\pi_t} + q_t^h (h_t^{I,i} - h_{t-1}^{I,i}) = \frac{W_t^{I,i}}{P_t} N_t^{I,i} + L_t^{I,i} + \mathcal{J}_t^{I,i}
\end{align*}$$

(7)

The impatient household are not able to save. Quite the reverse, to fund their housing demand, they have to negotiate a banking loan \(L_t^{I,i}\) at a nominal interest rate \(R_{t-1}^L\). The amount of period ‘t’ fund they can borrow is limited by the expecting value in ‘t+1’ of their housing stock that is required to guarantee repayment of the principal as well as the interests. This collateral constraint à la Kiyotaki and Moore (1997) is written as:

$$\begin{align*}
(1 + R_{t-1}^L) L_{t}^{I,i} \leq \mathbb{E}_t \left( \theta_t^I \left[ q_{t+1}^{I,i} \pi_{t+1} h_{t+1}^{I,i} \right] \right)
\end{align*}$$

(8)

where \(\theta_t^I\) is the loan-to-value ratio (LTV) required from households, it’s assumed to be constant.

### 3.2 Labor Market

The labor market is mainly composed of two unions, one for patient households and one for the impatient ones. Unions differentiate the aggregate level of labor issued by the corresponding type of households and sell its services in a monopolistically competitive market to a perfectly competitive firm which, using a CES technology function, transforms it into an aggregate labor input:

$$N_t^m = \left( \int_0^1 (N_t^{m,i}) \ \nu_{w-1}^{\nu_w} dt \right) \nu_w^{\nu_w-1}$$

where \(N_t^{m,i}\) is the differentiated type of labor brought by union \(i \in [0, 1]\) and \(\nu_w\) is the elasticity of substitution between differentiated labor services.

In addition, unions set their wages on a staggered basis à la ? in the sense that, at each period, every union faces quadratic adjustment costs when changing their wages. Each type of union has the following optimization program:

$$\max_{N_t^{m,i}, W_t^{m,i}} \mathbb{E}_t \sum_{k=0}^{\infty} \beta_k \gamma_{l+k} \left( \frac{W_{t+k}^{m,i}}{P_{t+k}} N_t^{m,i} - \frac{\nu_{w}^{\gamma_{l+k}^{\gamma_w-1}}}{2} \left( \frac{W_{t+k}^{m,i}}{W_{t+k-1}^{m,i}} - \pi_{l+k-1}^{1-\gamma_w} \pi_l^{1-\gamma_w} \right)^2 \frac{W_{t+k}^{m,i}}{P_{t+k}} \right) - \frac{(N_{t+k}^{m,i})^{1+\sigma_{n}}}{1 + \sigma_{n}}$$

subject to the following demand constraint:

$$N_t^{m,i} = \left( \frac{W_t^{m,i}}{W_t^m} \right)^{-\nu_{w}} N_t^{m}$$
3.3 Production

3.3.1 Entrepreneurs

In the economy there is a continuum of entrepreneurs. Each of them maximizes its own consumption $C_{t}^{E,j}$ by optimizing its utility function which is of the form:

$$W_{t}^{E,j} = \mathbb{E}_{t}\left[\sum_{k=0}^{\infty} \beta^{k} \left( \frac{C_{t+k}^{E,j} - \eta^{E}C_{t+k-1}^{E,j}}{1 - \eta^{E}} \right)^{1-\sigma^{E}} \frac{1}{1 - \sigma^{E}^c} \right]$$

and under the following budget constraint:

$$\frac{P_{t}^{E,j}}{F_{t}} Y_{t}^{E,j} + L_{t}^{E,j} + q_{t}^{K} K_{t-1} (1 - \delta) = C_{t}^{E,j} + w_{t}^{P} N_{t}^{P,j} + w_{t}^{I} N_{t}^{I,j} + \frac{(1 + R_{t-1}^{L,E}) L_{t-1}^{E,j}}{\pi_{t}}$$

$$+ q_{t}^{K} K_{t}^{j} + \psi(z_{t}) K_{t-1}^{j}$$

Each entrepreneur chooses the optimal stock of physical capital $K_{t}^{j}$ - as well as its utilization rate $z_{t}^{j}$ facing an adjustment cost $\psi(z_{t})$ - and the desired amount of labor inputs $N_{t}^{P,j}$ and $N_{t}^{I,j}$ that are combined to produce an intermediate output $Y^{E,j}$ according to a Cobb-Douglas production function:

$$Y^{E,j} = \left( K_{t-1}^{E,j} \right)^{\alpha} \left( (N_{t}^{P,j})^{\gamma_{P}} (N_{t}^{I,j})^{1-\gamma_{P}} \right)^{1-\alpha}$$

$L_{t}^{E,j}$ is the amount of firms’ external financing borrowed from banks. Similarly to the constrained households, this amount of bank lending is limited by the expected value of their undepreciated physical capital. This collateral constraint is thus written as:

$$(1 + R_{t}^{L,E}) L_{t}^{E,j} \leq \mathbb{E}_{t} \theta_{t}^{E} \left[ q_{t}^{K} \pi_{t+1} K_{t}^{j} (1 - \delta) \right]$$

3.3.2 Capital Producers

The main objective behind introducing the capital producers is to determine quite clearly the price of the physical capital. The physical capital market is composed by a capital producer evolving in a competitive market framework. At the beginning of each period, capital producer buy back the aggregated level of the undepreciated capital stocks $K_{t-1} (1 - \delta)$ at real prices (in terms of consumption goods) $q_{t}^{K,P}$. Then it augments this stock using investment goods but facing adjustment costs. The augmented stock is sold back to entrepreneurs at the end of the period at the same price. Thus, the decision problem of capital producer is given by:

$$\max_{K_{t},I_{t}} \sum_{i=0}^{\infty} \beta^{i} \lambda_{t+i} \left\{ (q_{t+i}^{K} K_{t+i} - q_{t+i-1}^{K} K_{t+i-1} (1 - \delta) - I_{t+i}) \right\}$$

taking into account the following cumulative technology function:

$$K_{t} = (1 - \delta) K_{t-1} + \left( 1 - \Gamma_{t} \left( \frac{I_{t}}{I_{t-1}} \right) \right) I_{t}$$
where $\Gamma_I \left( \frac{I_t}{I_{t-1}} \right)$ represent the standard quadratic adjustment costs when varying investment $I_t$:

$$\Gamma_I(x) = \frac{\phi}{2} (x - 1)^2 \quad (13)$$

### 3.3.3 Retail Market

The retail market is assumed to be monopolistically competitive. Retailers’ prices are sticky and are indexed to a combination of past and steady-state inflation, with relative weights parameterized by $\gamma^p$. In addition, if retailers want to change their price beyond what indexation allows, they face a quadratic adjustment cost parameterized by $\kappa^p$. Each firm $f \in [0, 1]$ chooses its sell price $P^f_t$ so as to maximize its market value:

$$\max Y_{f,t}, P^f_{t,t} \quad \mathbb{E}_t \sum_{k=0}^{\infty} (\beta_p)^k \lambda_{p,t+k} \left\{ \left( P^f_{t} - P^e_{t+i} \right) Y_{f,t+i} - \frac{\kappa^p}{2} \left( \frac{P^f_{t+k-1} - \pi^p_{t+k-1} - \pi^1 - \gamma_p}{\pi^t_{t+k-1} - \pi^1 - \gamma_p} \right)^2 P_{t+k} Y_{t+k} \right\}$$

subject to the demand derived from consumers’ maximization program à la Dixit-Stiglitz:

$$Y_{f,t} = \left( \frac{P^f_{t,t}}{P_t} \right)^{-\nu_g} Y_t$$

where $\nu_g$ is the demand price elasticity which is supposed to be constant.

In a symmetric equilibrium, the optimal choice for each retailer will be given by the (non-linear) Phillips curve:

$$\kappa^p \left( \pi_t - \pi^p_{t-1} \pi^1 - \gamma_p \right) \pi_t = 1 - \nu_p + \nu_p P^e_t + \beta_p \lambda_{t+1} \kappa^p \left( \pi_{t+1} - \pi^p_{t+1} \pi^1 - \gamma_p \right) \pi_{t+1} \frac{Y_{t+1}}{Y_t} \quad (14)$$

### 3.4 Banking Sector

According to Gerali et al. (2010) modeling framework, there are infinitely-lived representative banks $i \in [0, 1]$, each is composed of two main branches, namely a wholesale branch and a retail one. The last is itself composed of two subbranches that we will mention to as deposit and loan branches.

#### 3.4.1 The wholesale branch

Each wholesale branch has in charge the management of the balance sheet structure of the bank it belongs to. Indeed, the wholesale unit combines the savers deposit $D_t$ with cumulative bank capital $K^b_t$ to issue loans $B_t$ to the loan branch. The total amount of these assets $B_t$ is lent at a nominal rate $R^B_t$ when the deposits are borrowed from the deposit branch at a rate $R^{IB}_t$. $R^{IB}_t$ represents the interbank interest rate. Indeed, we suppose that the wholesale branch has an infinitely access to the money market funds where the main interest rate is the interbank rate. Moreover, we consider that interbank rate equal to the policy rate but, contrary to the latter, the interbank rate may be subject to an idiosyncratic shock characterized by a stochastic
volatility.

$$1 + R_t^{IB} = (1 + R_t) \varepsilon_t^{IB}$$

(15)

when $R_t$ is the policy rate and $\varepsilon_t^{IB}$ is an iid variable in the sense that:

$$\log (\varepsilon^{IB,t}) = \sigma_t^{\varepsilon^{IB}} \nu_t^{IB} \text{ where } \nu_t^{IB} \sim \mathcal{N}(0, 1)$$

(16)

with $\sigma^{\varepsilon^{IB}}$ is the standard deviation of the log of the interbank shock and is indexed by $t$. This means that the dispersion of the interbank shock changes over time. More precisely, we assume that $\sigma_t^{\varepsilon^{IB}}$ evolves over time as an auto-regressive process with the form:

$$\log \left( \frac{\sigma_t^{\varepsilon^{IB}}}{\sigma_0^{\varepsilon^{IB}}} \right) = \rho \log \left( \frac{\sigma_t^{\varepsilon^{IB}}}{\sigma_0^{\varepsilon^{IB}}} \right) + \eta \nu_t^{\sigma} \text{ where } \nu_t^{\sigma} \sim \mathcal{N}(0, 1)$$

(17)

where $\sigma_0^{\varepsilon^{IB}}$ is the steady-state value of the volatility $\sigma_t^{\varepsilon^{IB}}$, $\rho_\sigma$ represents the autoregressive coefficient of the log standard deviation and $\eta^\sigma$ the standard deviation of the innovations to volatility $\nu_t^{\sigma}$.

Furthermore, the structure of each bank balance sheet is subject to a regulatory constraint which states that the capital to assets ratio $K_b^t/B_t$ shall be not less than a given target value $\nu^b$. So, in its optimization program, each wholesale branch has to pay a cost $f(k^b_{t+i})$ whenever the actual capital to assets ratio is different from $\nu^b$. The wholesale branch objective is then:

$$\max_{D_t, B_t} \mathbb{E}_t \sum_{i=0}^{\infty} \beta^i \beta^P_t \left\{ R^b_{t+i} B_{t+i} - R_{t+i} D_{t+i} - f \left( \frac{K^b_{t+i}}{B_{t+i}} \right) K^b_{t+i} \right\}$$

(18)

under the accounting identity:

$$B_t = D_t + K^b_t$$

(19)

Note that when Gerali et al. (2010) chose a quadratic cost function for $f$, we rather prefer a more sophisticated function at least for two reasons. First, we choose to model a more realistic cost function with a positive cost when the capital to assets ratio is below the regulatory threshold and a negative cost when it is above the threshold. Indeed, by holding more capital, banks reduces potential bankruptcy costs (Warner (1977)). However, getting large amount of capital represent also an opportunity cost that makes finally the cost function not monotonic. Second, and using the non-monotonicity of the cost function, we are also able to model an endogenous capital buffer. According to all these reasons, we choose $f$ to be of the form:

$$f(k^b_{t,i}) = \kappa_b \left\{ \gamma^b \left[ (k^b_{t,i})^{-1/\xi_b} - (\nu^b)^{-1/\xi_b} \right] + (k^b_{t,i} - \nu^b)^{2} \right\} \quad (\kappa_b, \xi_b, \gamma^b) \in (\mathbb{R}^{+,*})^3$$

(20)

Solving the wholesale branch program, the FOC results in an equation linking the spread $(R^b_t - R_t^{IB})$ to the leverage ratio $k^b_{B,t}$:

$$R^b_t - R_t^{IB} = \kappa^b_{k^b_{B,t}} \left\{ \gamma^b_{k^b_{B,t}} (k^b_{B,t})^{-1/\xi_b - 1} - 2 (k^b_{B,t} - \nu^b) \right\}$$

(21)
At the steady state, the right hand of the previous equation is equal to 0 which induces a steady-state bank capital to assets ratio as:

\[ k_B = \nu_b + \left( \frac{\gamma b}{\xi b} \right) \frac{1}{\xi b - 1} \]  

(22)

Merging equation (22) with equation (21), we can assess the following relation:

\[ R_b t - R_{IB} t = \kappa b \left[ \frac{\gamma b}{\xi b} \left( k_{B,t} \right) \frac{1}{\xi b - 1} - \frac{\gamma b}{\xi b} \left( k_B \right) \frac{1}{\xi b - 1} - 2 \left( k_{B,t} - k_B \right) \right] \]  

(23)

This equation is similar to what Gerali et al. (2010) found with a quadratic cost function. However, we allow in our specification asymmetric costs around the steady-state when quadratic costs do not. Indeed, if \( \gamma b \) controls for the steady-state value of the capital buffer (see eq. (22), the parameter \( \xi b \) affects the degree of asymmetry around the steady-state level. With this new specification, banks are less depressed when their capitalization ratio rises than when it decreases with a same amount.\(^6\) This behavior is of particular interest when dealing with uncertainty shocks as we analyze later.\(^7\)

Finally, the law of motion of bank capital is of the form:

\[ \pi_t K^b_t = (1 - \delta^b) K^b_{t-1} + J^b_{t-1} \]  

(24)

where \( \delta^b \) represents the proportion of last period bank capital used in managing the bank capital and \( J^b_t \) the overall profits made by the wholesale unit as well as the retail one with its two subbranches.

### 3.4.2 The retail branch

The retail branch is composed of a unit mass of banks \( j \in [0, 1] \) which evolve in a monopolistic market framework with nominal rigidities à la Rotemberg. Their main activity consists in offering financial services to both households and firms (entrepreneurs). These services are of two types: collecting deposits from savers (deposit branch) and lending funds to both impatient households and entrepreneurs (loan branch).

#### The deposit branch

The retail deposit branch of bank \( i \) raises deposits from patient households and remunerate them at \( R^{d,j}_t \). As mentioned in the previous section, all these collected deposits are lent to the wholesale branch at a nominal rate \( r_t \). Exploiting its market power, the deposit branch chooses the optimal interest rate \( R^{d,j}_t \) that maximizes its profit taking into account a finite elasticity of

---

\(^6\)According to our baseline calibration, a decrease in capital ratio by 0.5% (in level) generates a 18% larger response in the interbank rate than what does an increase of the capital ratio by 0.5%

\(^7\)Note also that since the resolution method requires a third order approximation, this asymmetry is still present.
deposit supply. The deposit branch decision program boils down to:

$$
\max_{D^L_t, R^{D,j}_t} \mathbb{E}_t \sum_{k=0}^\infty \beta^k \lambda^p \left\{ \left( R^{IB}_{t+k} - R^{D,j}_{t+k} \right) D^j_{t+k} - \frac{\kappa_d}{2} \left( \frac{R^{D,j}_{t+k}}{R^{D,j}_{t+k-1}} - 1 \right)^2 \frac{R^{D,j}_{t+k} D_{t+k}}{D_t} \right\}
$$

(25)

$D^j_t$ represent the part of the aggregated deposit supply $D_t$ raised by bank j which is also a solution of the following equation:

$$
D^j_t = \left( \frac{R^{D,j}_t}{R^D_t} \right)^{-\nu_D} D_t
$$

(26)

where $\nu_D$ is the constant supply price elasticity.

The solution of the deposit branch programme involves the choice of a deposit rate which is of the form:

$$
R^D_t = - \frac{\nu_D}{1 - \nu_D} R^{IB}_t
$$

$$
- \left\{ \kappa_d \left( \frac{R^D_t}{R^D_{t-1}} - 1 \right) - \lambda_p^t \lambda^p \beta_p \left( \frac{R^{D,j}_{t+1}}{R^D_t} - 1 \right) \left( \frac{R^{D,j}_{t+1}}{R^D_t} \right)^2 \frac{D_{t+1}}{D_t} \right\} R^D_t
$$

(27)

The loan branch

Similarly, the loan branch of bank j borrows funds from the wholesale branch at $R^B_t$ in order to lend them to households and firms. Thus, the corresponding optimization program can be written as:

$$
\max_{L^L_{t+k}, R^{L,j}_t, L^{E,j}_t} \mathbb{E}_t \sum_{k=0}^\infty \beta^k \lambda^p \left\{ R^{L,j}_{t+k} L^L_{t+k} + R^{L,E,j}_t L^{E,j}_{t+k} - R^b_t B^j_{t+k} \right\}
$$

$$
- \frac{\kappa_l}{2} \left( \frac{R^{L,j}_t}{R^{L,j}_{t+k-1}} - 1 \right)^2 R^{L,j}_{t+k} L^{L}_{t+k} - \frac{\kappa_l}{2} \left( \frac{R^{L,E,j}_t}{R^{L,E,j}_{t+k-1}} - 1 \right)^2 R^{L,E,j}_t L^{E}_{t+k}
$$

(28)

under the accounting identity:

$$
B^j_t = L^{E,j}_t + L^L_{t,j}
$$

(29)

as well as the demand equations from impatient households and entrepreneurs:

$$
L^L_{t,j} = \left( \frac{R^{L,j}_t}{R^{L,I}_t} \right)^{-\nu_{L,j}} L^I_t
$$

(30)

$$
L^{E,j}_t = \left( \frac{R^{E,j}_t}{R^{L,E}_t} \right)^{-\nu_{L,E}} L^E_t
$$

(31)

where $\nu_{L,j}$ and $\nu_{L,E}$ are respectively the households and entrepreneurs demand price elasticities.

For each type of asset $A = \{I, E\}$, the interest rates’ law of motion is in a symmetric equilibrium of the form:

$$
R^A_t = \frac{\nu^A}{\nu^A - 1} R^B_t
$$

$$
- \left\{ \kappa^A \left( \frac{R^A_t}{R^A_{t-1}} - 1 \right) - \lambda_p^t \lambda^p \beta_p \left( \frac{R^{A}_{t+1}}{R^A_t} - 1 \right) \left( \frac{R^{A}_{t+1}}{R^A_t} \right)^2 \frac{L^A_{t+1}}{R^A_t} \right\} R^A_t
$$

(32)
3.5 Monetary Policy & Market clearing conditions

Monetary policy is specified in terms of an interest rate rule targeting inflation, its first difference as well as the first difference in output. The Taylor interest rate rule used has the following form:

\[
1 + R_t = (1 + R_{t-1})^{\rho_R} \left[ (1 + \bar{R}) \left( \frac{\bar{\pi}_t}{\pi_t} \right)^r \left( \frac{Y_t}{Y_{t-1}} \right)^{\Delta Y} \right]^{1-\rho_R} \varepsilon_{R,t} \quad (33)
\]

where \( r_\pi \) is the weight assigned to inflation and \( \Delta Y \) that assigned to output growth. \( \bar{R} \) is the steady-state policy rate and \( \varepsilon_{R,t} \) is the monetary policy shocks. The law of motion of \( \varepsilon_{R,t} \) is assumed to be as:

\[
\log(\varepsilon_{R,t}) = \sigma^e \nu_t^e \text{ where } \nu_t^e \sim \mathcal{N}(0,1) \quad (34)
\]

\( \sigma^e \) is the standard deviation of the log monetary policy shocks which is considered as constant.

Aggregating all the agents’s budget constraints, we set the following market clearing condition in goods market:

\[
C_t^P + C_t^I + C_t^E + Q_k^t I_t \left( 1 - \Gamma \left( \frac{I_t}{I_{t-1}} \right) \right) + \psi(z_t)K_{t-1} + \delta^b K_{t-1}^b + Adj_t^{NB} + Adj_t^B = Y_t \quad (35)
\]

where \( Adj_t^B \) and \( Adj_t^{NB} \) include all adjustment costs in banking and non-banking sectors.

4 Calibration

Table 3 summarizes our calibration choices. We fix several parameters to values in the range suggested by Gerali et al. (2010) estimation or calibration. Thus, with respect to households inter-temporal elasticities, we set \( \sigma_c^m = 1 \), \( \sigma_h^m = 1 \) and \( \sigma_n^m = 1 \) for both patient and impatient households \( m = P, I \). The same applies for the parameters related to nominal rigidities as well as all other Phillips curve parameters for both good and labor market. Finally, the share of the impatient households \( (1 - \gamma_n) \) was set at 0.2 in accordance with Gerali et al. (2010) calibration.

For some other parameters, we chose to set their values in order to pin down the steady-state values of some variables. We computed the steady-state values as the mean of the variable of interest on the sample starting from the beginning of 2003 until the mid of 2008, this choice of the sample is subject, on the one hand, to data availability and, on the other hand, to our willingness not to take into account the post Lehman Brothers collapse that triggered unusual variations in most financial variables. Using this strategy, we calibrate several parameters including some fundamental parameters such as the LTV ratios for households and entrepreneurs (\( \theta^b \) and \( \theta^e \)), as well as the households discount factor parameter \( \beta_p \) or the elasticities of the loans demand (resp. deposit supply) to the corresponding bank lending rates (resp. deposit rate). Moreover, we set the required level of banks capitalization ratio \( \nu^b \) at 4.5% which corresponds to the Basel III "minimum common equity capital" ratio final objective, when the regulatory cost function parameters \( \xi_b \) and \( \gamma_b \) were fixed at 1 and 0.0013 respectively, which corresponds to a steady-state capital ratio 10.5% in line with the Basel III "minimum total capital plus conservation buffer" ratio.
For other parameters such as the weights of bank rates rigidities \((\kappa_{d}, \kappa_{l_e} \text{ and } \kappa_{l_i})\) for which the calibration is more problematic, our calibration scheme was oriented towards the empirical literature. Therefore, we set the values of the previously mentioned parameters in a way that is consistent with the shape of the impulse response function of bank deposit/lending rates to a market interest rate shock which had been obtained from a SVAR using euro area data in de Bondt (2005).

Concerning the volatility shocks parameters, we set the auto-regression coefficient \(\rho_{\sigma}\) at 0.95 when the steady-state value of \(\sigma_{t}^{2}\) is equal to 0.125% which means that a one standard deviation shock on \(\nu_{t}^{r}\) corresponds to a 50 bp rise in the annual policy rate. Finally, we put \(\eta_{\sigma}\) at 0.1 which means that starting at the steady-state interbank rate (3% in annual term), a simultaneous one-standard-deviation innovation to the rate with a one std shock to its volatility, the interbank rate jumps by about 56 bp rather than by 50 bp in the absence of volatility shocks.

5 Impulse response functions analysis

5.1 Level shock

Figure 2 shows the impulse response functions (IRFs) to a monetary policy shock, more precisely, an unanticipated 50 bp (on annual basis) increase in the monetary policy rate. The responses of interest rates, interest rate spreads and inflation are expressed in percentage points from their ergodic means while the responses of other variables are expressed in percent deviation from their ergodic means. The main objective of Figure 2 is to highlight that the calibrated model replicates standard stylized facts concerning the monetary policy transmission and more particularly concerning the interest rate pass-through.

First, we observe that banks’ depositors receive a higher remuneration while banks’ borrowers face more costly credit terms following the shock. The immediate pass-through from the policy rate to the retail rates are nevertheless incomplete. Furthermore, according to the calibration, rigidities are stronger on the deposit rate than on the loan rates. The policy rate increases by about 12 bp (in quarterly basis) when the shock occurs and leads to a 1.5 bp increase in the deposit rate while the loan rates increase respectively by 2.2 bp for households and by 3.7 percentage point for firms. As a result the immediate interest rate pass-through is around 13% for the deposit rate, 20% for the loan rate to households and 33% for the loan rate to firms. The size of these immediate adjustments in the retail rates is in line with the empirical literature (Mojon (2000), de Bondt (2005)).

During the following periods, the policy rate returns quickly to its ergodic mean when, conversely, the retail rates still increase during one more period and then progressively turn down to their ergodic means, which highlights the sluggishness in the retail rates adjustments. For example, the impulse response of the lending rate to firms rise to 4.7 bp one period following the shock while impulse response of the policy rate is reduced to 7.3 bp. These differences are highlighted by the IRF of the firms loans-policy rate spread on Figure 2. This spread is negatively affected by the shock due to the incomplete

\footnote{Note that in the model, there is no difference between the policy rate and the money market rate at the equilibrium. In addition, the long run pass-through is given by the steady state equations. The long run pass-through is then different from 1 but depends on the mark-ups for the loan rates and depends on the mark-down for the deposit rate.}
immediate pass-through but turns slightly positive four periods following the shock due to the central bank’s reaction and to the rigidities in bank interest rates. Considering banks’ activities as a whole, Figure 2 shows a contraction in the credit and deposit volumes but the loan-deposit margins increase. Banks’ profits and thus banks’ equities increase following the shock.

Second, price stickiness implies that impatient households and entrepreneurs face higher real borrowing costs. Consequently, the user costs of capital and housing rise; the demands for these assets fall and then asset prices decline. This downward movements in asset prices reinforces the credit constraints which lead therefore to a drop in banks lending and then to a downward adjustment in consumption and investment. In turn, patient households receive a higher real deposit rate. However, they reduce their deposit holdings as well as their consumptions, mainly due to intertemporal substitution effects. As a result, the monetary policy shock generates a drop in GDP that reaches a trough about 0.18% three periods after the shock. This value is quite lower than what we can find with standard new keynesian models even if they lack the amplification mechanism à la K&M. Indeed and as pointed out by Gerali et al. (2010), the sluggishness of loan rates reduces the contraction of real variables since the transmission to the real sector of the contractionary monetary policy is smoothed across periods.

5.2 Volatility shock

The introduction of stochastic volatility in a New Keynesian framework has been considered notably by Fernández-Villaverde and Rubio-Ramírez (2010) who highlight the importance of time-variant volatilities to account for macroeconomic fluctuations. Fernández-Villaverde et al. (2011) and Fernández-Villaverde et al. (2012) have more particularly focused their studies on the country spread and of fiscal volatility shocks. In this paper, we focus on an interbank rate volatility shock as well as on its implications for the interest rate pass-through.

Figure 3 represents the impact of a two-standard deviation uncertainty shock to the interbank lending rate.9 Focusing on the differences between the IRFs for the three scenarios considered, we can see how the second and third order terms induce strong non-linearities in the responses with the latter increasing more than proportionally to the size of the shock. We remark also the non negligible impact of financial uncertainty on the key real variables. Indeed, rational agents in the model react to the fact that future shocks will be drawn from a larger distribution and this will be true for many periods according to the high volatility shocks persistence. As a consequence, they react in a way that makes the potentially large shock as painless as possible. Indeed, a two standard-deviation interbank volatility shock triggers a drop in the overall output that reaches a low about -0.5% six quarters after the shock. This drop is equally driven by the decline in consumption and investment, each dropping by around 0.5%. Born and Pfeifer (2011) found that a shock to the policy rate volatility has a contractionary effect on output that is mostly driven by the collapse in investment when consumption reacts sluggishly.

9For a matter of comparison, we also show the impulse responses of 4 and 7 standard deviations shocks to $\nu$. Starting from the steady-state value, an eventual 2 standard deviations change in the interbank rate would then represent a ± 0.62% when 4 and 7 std shocks would respectively represent around ± 0.75% and ± 1.0% variation of the interbank rate.
Their model lacks however financial frictions that play a key role in the transmission mechanism of shocks. Indeed, in times of high volatility, households adopt a precautionary behavior that consists in diminishing their demand for consumption goods as well as their ability to invest in residential goods. This induces a drop in housing prices which in turn affects the ability of borrowing households to get funds from banks. The collateral constraint will thus play an amplification role that accentuate the positive correlation between house prices (or bank loans) and consumption. A similar mechanism arises for firms that witness tighter bank lending conditions through the decline in capital prices. Thus, we note that for the 2std shock, the bank loans to both households and firms decline by about 0.53% and 0.2% respectively when in the same time the corresponding interest rates go up. Indeed, a key result of an interbank rate volatility shock is the stagflationary effect that we note in most of the models’ market. This result is similar to the one obtained by Fernández-Villaverde et al. (2012) using fiscal volatility shocks. According to the contractionary effect of uncertainty shocks, we would legitimately expect a downward pressure on prices. However, the impulse responses on Figure 3 indicate an upward trend in most of the prices in the economy, including the banking markets. Indeed, we observe from the impulse responses of interest rates spreads that the mark-up policy chosen by banks changes from what we would expect and also from what we have seen for a standard monetary policy shock. Focusing on this point, it should be noted that the increase in the bank lending rates spreads indicates that the pass-through from the policy rate to the bank lending rates are larger than unity. The monetary policy rate slightly increases following the volatility shock due to the stagflationary situation inducing a rise in firms lending rate. However, the spreads also increases and reach its maximum of 0.2 bp 1.5 year following the shock.

Fernández-Villaverde et al. (2012) define an upward pricing bias channel to explain this upward trend in prices and corollary the stagflation situation. This channel, based on nominal rigidities, gives a particular importance to adjustment costs. Indeed, according to Fernández-Villaverde et al. (2012), under uncertainty, profits are less impacted in terms of adjustment costs if prices are too high than if prices are too low. Goods retailers increase therefore their mark-up following the shock and inflation goes up. However, according to the impulse responses, we also found an upward pricing bias for the deposit branch of the banking sector when these "marginal cost makers" are supposed to lower their marginal cost according to Fernández-Villaverde et al. (2012) explanation. In this paper, we propose an alternative explanation to the change in mark-ups policy which is not necessary upward. As Fernández-Villaverde et al. (2012) claimed, the upward trend in prices is totally due to the presence of adjustments costs. Indeed, fearing to be hit by a large shock and factoring into that each price change will be costly, the optimizing agents decide to react in order to make the adjustment costs as low as possible. Moreover with the nominal rigidity à la Rotemberg, which considers adjustment costs to be proportional to the prices growth rate, to reach an optimal price it will be less costly to start from a high level of price than the inverse since with the same growth rate, then at the same cost, an optimizing agent would reach a closer price to the optimal one if he starts at a high level than at a low one. In Appendix 7, we give more insights on the intuition behind this

\footnote{The deposit rate is not strictly speaking the marginal cost of the deposit brunch. We nevertheless will abusively use the "marginal cost maker" expression for a matter of simplicity.}
result. Still, it is important to note that this upward pricing pressures are not systematic, they seem depending on the specification of the nominal rigidity process that one chooses. However, testing different types of nominal rigidities specifications, we found that most of them generate this upward pressure on prices which in consequence should not alter the conclusions of our paper nor those of Fernández-Villaverde et al. (2011) and Fernández-Villaverde et al. (2012).

6 The transmission of the monetary policy in time of interbank uncertainty

6.1 A standard calibration

In this section, we assess the impact of the interbank market uncertainty on the transmission of the monetary policy. For that purpose, we generate the IRFs to two simultaneous shocks; the first one on the policy rate level and the second one on the volatility of the interbank rate.

The choice of the size of the shocks matters because we are dealing with a third order approximation (and thus non-linear) form of our model. In the baseline calibration, the standard deviation of the monetary market rate was set to a low level in line with the degree of volatility observed up to 2007. We represent therefore the increase in the interbank market uncertainty by a 7 standard deviations shock in the innovations of the standard deviation of the interbank rate \((\nu\sigma)\). This value seems high when actually it means that a potential one std interbank change would correspond to \(\pm 1\%\) variation which has been witnessed several times in the last 2 decades. Concerning the shock on the policy rate, we consider an accommodative monetary policy that we define as a 50 basis point decrease in the interest rate. The impulse response functions are reported on Figure 4. To make the interpretation easier, we also report on Figure 4 the impulse response functions obtained following a 50 basis point decrease in the interest rate without any shock on the interbank rate volatility.

We note the transmission of the monetary policy to the real economy is initially not affected by the rise in the interbank uncertainty. However, except for the first period, Figure 4 shows some discrepancies between the impulse responses due to the inclusion, or not, of the volatility shock. We also note that the financial variables are those that are the most affected by the interbank volatility when the real variables carry much less of the volatility shock. This means that the banking sector filter the volatility shocks as it does with policy ones. This result is also in line with our finding in section 2.2 as well as Scharler (2008) conclusions.

Concerning the interest rate pass-through, the deposit rate and the loan rates for households and firms decrease respectively by 0.015, 0.021 and 0.038 percentage point following the 0.11 percentage point reduction in the policy rate when the two shocks occur simultaneously. The immediate interest rate pass-through is then around 12.5% for the deposit rate, 19% for the loan rate to households and 31.5% for the loan rate to firms, which is slightly lower than the immediate interest rate pass-through observed when the interbank rate uncertainty remain at a low level. In addition, the differences between the IRFs for the retails interest rates increase during the periods 2 and 3. The transmission of the expansionary monetary policy to the retail interest rates is therefore noticeably reduced by the rise in the interbank rate volatility. The slow down in the interest rate pass-through identified during the 2007-2008 financial crisis (IMF 17
(2008), Čihák et al. (2009), Aristei and Gallo (2012) and Hristov et al. (2012)) can therefore be explained by an interbank rate volatility shock occurring simultaneously with the monetary policy easing. Finally, due to the persistence in the interbank rate volatility shock and due to the stagflationary effects generated by this kind of shock, the IRFs of retail interest rate turn positive six periods following the shocks when the effects of the monetary policy easing are lessening.

As a consequence, we can see from the IRFs for spreads on Figure 4 that the lending margins increase while the deposit margins decreases. The upward pressures on prices generated by the volatility shock moderate therefore the drop in banks profits. Banks can rebuild their capital positions in relatively few quarters after the shocks. However, this resumption in banks benefits comes with a drop in deposits and lending activities. All of these evolutions were observed in the euro area following the financial crisis (ECB (2012)).

6.2 The impact of structural parameters

In the previous subsection, we showed that for a standard set of parameters calibration, the transmission of the monetary policy to the real economy is affected by the degree of volatility in the interbank market. More precisely, the expansionary effect of a monetary policy easing and the interest rate pass through are weakened by a rise in the interbank rate volatility. In this subsection, we proceed to a sensitive analysis and we focus more particularly on the central bank behavior. The main objective is to evaluate if the disruption in monetary policy transmission generated by the volatility shock is reduced when the central bank behaves differently.

However, changes in structural parameters affect the effects both of the monetary policy easing and of the interbank volatility increase. As a result, to disentangle the effects generated by the change in the standard deviation from the effects generated by the change in the level, we use the following approach. First, we set different values for a structural parameter. Second, for each calibration, we compute the IRFs relatively to the two scenarios described in the previous subsection, i.e. the IRFs of an accommodative monetary policy with or without a modification of the interbank rate volatility. Third, we compute the relative difference in percentage between the two impulse responses.\(^\text{11}\) This relative difference highlight to which extent the interbank volatility shock disrupts the effect of an accommodative monetary policy. More precisely, a positive value means that the volatility shock amplifies the monetary policy easing while a negative value indicates that the monetary policy easing is mitigated. In addition, a negative value lower that -100% indicates a sign inversion in the impulse response generated by the volatility shock.

6.2.1 Weight on inflation in the Taylor rule

The central bank could have the incentive to modify its reaction function if these modifications could improve the stabilizing powers of monetary policy. The interbank rate volatility shock is characterized by upward pressures on prices. We start therefore to consider a modification in

\(^\text{11}\)For a given calibration, if \(IRF_{X,t}^{\text{level+volat}}\) is the IRF for variable \(X\) in period \(t\) when the shocks on level and volatility occur simultaneously and \(IRF_{X,t}^{\text{level}}\) is the IRF when only the level shock is considered, then we compute \((IRF_{X,t}^{\text{level+volat}}-IRF_{X,t}^{\text{level}})*100/IRF_{X,t}^{\text{level}}\).
the Taylor rule coefficient on inflation. The results are reported on Figure 5. More precisely, the relative differences are reported for the baseline calibration \( r_\pi = 2 \) and for calibrations with a lower \( r_\pi = 1.5 \) and a higher \( r_\pi = 3 \) or 5 \) weight on inflation. Furthermore, we do not report the IRFs for all the variables but we rather focus on the situations of firms in order to save space.\(^{12}\) We find that a more conservative strategy of the monetary authority, \textit{ceteris paribus}, strengthens the disrupting effect of the interbank rate volatility shock on the real economy. Figure 5 shows that the relative differences for loans to firms, investment and GDP, obtained with a more conservative central bank, are negative and below the ones obtained in the baseline calibration. Conversely, these relative differences are above the baseline situation when a less conservative central bank is considered. Indeed, as volatility shocks trigger inflation pressures in the economy, a central bank that mainly focuses on inflation will have more incentives to minimize its accommodative policy and will likely raise the policy rate more quickly. This will in turn put an additional upward pressure on bank lending rates, leading to a higher drop in bank loans and, at the end, investment and production. The main implication is that the volatility shock disrupts in a higher extent the interest rate pass-through as we can remark it to the graph relative to the loan to firms-policy rates spread on Figure 5. Finally, Figure 5 shows that the more conservative central bank get the inflation pressures generated by the volatility shock under control. The relative differences for inflation are closer to 0 and turn even negative when the weight on inflation in the Taylor rule is set to 3 or 5.

In conclusion, the degree of interest pass through is less resilient to the presence of volatility shock when the central bank is more conservative. In turn, the real economy benefit in a lower extent of the accommodative monetary policy shock.

6.2.2 Weight on GDP in the Taylor rule

In the baseline calibration, the central bank does not react to the GDP growth rate. The GDP weight is set to 0 in the Taylor rule. We can therefore investigate the consequences of a more balanced monetary policy including both GDP and inflation stabilization objectives. Figure 6 shows the results corresponding to different calibrations of the weight of the output variation in the Taylor rule \( r_{\Delta Y} \): the relative differences are reported for the baseline calibration \( r_{\Delta Y} = 0 \) and for calibrations with a positive weight on GDP \( r_{\Delta Y} = 1, 2 \) or 5). The key result is that the impact of the financial uncertainty is very sensitive to the (semi) elasticity of policy rate to GDP. However, this relationship is not intuitive especially in the case of an accommodative monetary policy. Indeed, recall that the volatility shocks are stagflationnary, which means that a pure volatility shock has an ambiguous impact on the policy rate depending on the elasticity of policy rate to GDP. On the one hand, with a large elasticity, the monetary authority will be induced to decrease its rate after a volatility shock. This general equilibrium mechanism dampens largely the volatility shock effect. On the other hand, with a small elasticity to GDP growth, the policy rate initially increases after a pure volatility shocks which induces a larger negative impact on GDP. Thus, in time of accommodative monetary policy, a higher negative impact on GDP will reduce the GDP growth initially which in turn generates a smaller response from monetary authority according to its sensitivity to GDP. When in case of high elasticity,

\(^{12}\)The conclusions can however be generalized to loans to households and to deposits activities. The whole set of IRFs is available upon request.
the lower negative effects of a pure volatility shocks combined to the large elasticity to GDP will induce a larger initial cut-off in interest rates. In consequence, larger the sensitivity of policy rate to GDP larger will be the amplification effects of volatility shocks initially (see. Fig. 6). In the second half of our simulation period, the contribution of the volatility shocks starts increasing which induces negative pressure on the GDP and, in turn, gives incentives to monetary authority to ease its policy comparatively to what it would do in the absence of GDP sensitivity. The monetary authority moderates again the amplitude of most variables variations, the moderation degree being again very sensitive to the change in the policy rate and thus in to the general equilibrium channel. Fig. 6 shows how a more balanced monetary policy is less affected by volatility shocks which, in turn, limits the amplification of volatility shocks.

6.2.3 Smoothing parameter in the Taylor rule

The central bank behavior is also characterized by the monetary policy smoothing parameter. In particular, an important feature following the monetary policy easing in 2007-2008 was the tendency initiated by the Federal Reserve of smoothing its monetary policy for a long period in order to keep the policy rate at a low level. We thus calibrate the policy-rate auto-correlation coefficient to different values ($\rho^R=0.1$, $0.5$, $0.8$ and $0.98$) and we implement the same exercise as previously. Figure 7 shows that a more pronounced smoothing by the central bank can reduce the disrupting effect of the interbank rate volatility shock on the real economy. The relative difference for a smoothing parameter fixed at 0.98 is above the relative difference of the baseline calibration for loans to firms and for GDP. Indeed, following the monetary policy easing, agents expect that the policy rate will be adjusted upward very progressivly. The expansionary effect on the real economy is then magnified which offset the consequences of the change in the interbank rate volatility. However, the persistence in the policy rate and the evolution of aggregate demand lead to an amplification of the inflationary pressures. Figure 7 shows that the relative difference for inflation is positive and above the baseline calibration when the smoothing parameter is high. These difficulties to keep inflation under control are the costs inherent in stabilizing the real sector.

7 Conclusion

Several empirical papers conclude that the interest rate pass through slowed down during the 2007-2008 financial crisis (IMF (2008), Čihák et al. (2009), Aristei and Gallo (2012) and Hristov et al. (2012)). However, very few structural approaches have been developed to explain these empirical findings. Only Hristov et al. (2012) show that a modification in the frictions characterizing the banking sector, as for example tighter collateral requirements, can dampen the interest rate pass-through. In this paper, we rather focus on the interbank volatility. We point out that, during a financial crisis, banks cannot mute the consequences of an interbank rate volatility shock. As a results, retail interest rates and more generally the real economy can be affected by the time-variant interbank rate volatility.
We find that an interbank rate volatility shock has a stagflationary effect. Considering fiscal volatility shocks, Fernández-Villaverde et al. (2012) already showed that volatility shocks can have a stagflationary effect. However, we provide an alternative explanation to the upward pressure on prices generated by a volatility shock. Our approach points out to the role of nominal rigidities specification in the interpretation of agents behavior.

Concerning the interest rate pass-through, we show that an interbank rate volatility shock disrupts the effect of a monetary policy easing. More precisely, following the cut of the policy rate, the downward adjustments of the retail interest rates are dampened because the rise in the interbank rate volatility generate upward pressures on all the prices in the economy. In addition, we show that a more conservative central bank would not perform better. The upward pressures on prices would be more aggressively managed, the degree of interest rate pass-through would be less stable, and the economic slowdown would be larger. A central bank with a more balanced monetary policy, reacting both to inflation pressures and to GDP variations, would be then in a better situation to deal with the consequences of an interbank rate volatility shock.
References


Roelands, S. (2013). Asymmetric interest rate pass-through from monetary policy: The role of bank regulation. mimeo, University of Notre Dame.


### Table 1: Long-run relationships

#### Mean equations

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>$\Delta \text{Euribor}_{t}^{1Y}$</th>
<th>$\Delta r_{t}^{L}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_{10}$</td>
<td>0.9852***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.1811)</td>
<td></td>
</tr>
<tr>
<td>$b_{11}$</td>
<td>0.8216***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0600)</td>
<td></td>
</tr>
<tr>
<td>$b_{20}$</td>
<td>1.3898***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.1676)</td>
<td></td>
</tr>
<tr>
<td>$b_{21}$</td>
<td>0.8397***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0491)</td>
<td></td>
</tr>
</tbody>
</table>

| $R^{2}$            | 0.89                            | 0.89               |

Phillips-Ouliaris $\tau$-stat: -3.07* -4.14***
Phillips-Ouliaris $z$-stat: -18.05* -21.16**

Note: ***, ** and * indicate significance respectively at the 1%, 5% and 10% levels. Standard errors are in brackets.

### Table 2: Short-run specification

#### Mean equations

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>$\Delta \text{Euribor}_{t}^{1Y}$</th>
<th>$\Delta r_{t}^{L}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_{10}$</td>
<td>-0.0005</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0075)</td>
<td></td>
</tr>
<tr>
<td>$k_{11}$</td>
<td>0.5717***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0610)</td>
<td></td>
</tr>
<tr>
<td>$k_{12}$</td>
<td>0.1123**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0569)</td>
<td></td>
</tr>
<tr>
<td>$k_{13}$</td>
<td>-0.0474**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0195)</td>
<td></td>
</tr>
<tr>
<td>$k_{20}$</td>
<td>-0.0087</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0054)</td>
<td></td>
</tr>
<tr>
<td>$k_{21}$</td>
<td>0.2927***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0667)</td>
<td></td>
</tr>
<tr>
<td>$k_{22}$</td>
<td>0.2058***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0391)</td>
<td></td>
</tr>
<tr>
<td>$k_{23}$</td>
<td>-0.0845***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0148)</td>
<td></td>
</tr>
</tbody>
</table>

| $R^{2}$            | 0.47                            | 0.49               |

Note: ***, ** and * indicate significance respectively at the 1%, 5% and 10% levels. Standard errors are in brackets.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_c^P$</td>
<td>Inter-temporal elasticity of substitution of patient households consumption</td>
<td>1</td>
</tr>
<tr>
<td>$\sigma_I^I$</td>
<td>Inter-temporal elasticity of substitution of impatient households consumption</td>
<td>1</td>
</tr>
<tr>
<td>$\eta^P$</td>
<td>Habit in patient households consumption coefficient</td>
<td>0.6</td>
</tr>
<tr>
<td>$\eta^I$</td>
<td>Habit in impatient households consumption coefficient</td>
<td>0.6</td>
</tr>
<tr>
<td>$\sigma_n^P$</td>
<td>Inverse of the Frisch elasticity for patient households</td>
<td>1</td>
</tr>
<tr>
<td>$\sigma_n^I$</td>
<td>Inverse of the Frisch elasticity for patient households</td>
<td>1</td>
</tr>
<tr>
<td>$\sigma_h^P$</td>
<td>Inter-temporal elasticity of substitution of patient households housing demand</td>
<td>1</td>
</tr>
<tr>
<td>$\sigma_h^I$</td>
<td>Inter-temporal elasticity of substitution of impatient households housing demand</td>
<td>1</td>
</tr>
<tr>
<td>$\theta^I$</td>
<td>The LTV ratio for impatient households</td>
<td>0.1</td>
</tr>
<tr>
<td>$\gamma_w$</td>
<td>Wage indexation on last period inflation rate</td>
<td>0.3</td>
</tr>
<tr>
<td>$\kappa_w$</td>
<td>Wage adjustment cost</td>
<td>70</td>
</tr>
<tr>
<td>$\sigma_c^E$</td>
<td>Inter-temporal elasticity of substitution of entrepreneurs consumption</td>
<td>1</td>
</tr>
<tr>
<td>$\eta^E$</td>
<td>Habit in entrepreneurs consumption coefficient</td>
<td>0.6</td>
</tr>
<tr>
<td>$\theta^E$</td>
<td>The LTV ratio for entrepreneurs</td>
<td>0.075</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Capital share in the production function</td>
<td>0.33</td>
</tr>
<tr>
<td>$\gamma_n$</td>
<td>the share of the impatient households</td>
<td>0.8</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Capital depreciation rate</td>
<td>0.025</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Capital producers investment adjustment cost</td>
<td>1</td>
</tr>
<tr>
<td>$\xi_2$</td>
<td>Parameter of adjustment cost for capacity utilization</td>
<td>0.00478</td>
</tr>
<tr>
<td>$\nu_g$</td>
<td>$\frac{\nu_g}{\nu_g - 1}$ is the mark-up in the good market</td>
<td>6</td>
</tr>
<tr>
<td>$\gamma_p$</td>
<td>Price indexation on last period inflation rate</td>
<td>0.15</td>
</tr>
<tr>
<td>$\kappa_g$</td>
<td>Price adjustment cost</td>
<td>30</td>
</tr>
<tr>
<td>$\kappa_b$</td>
<td>The weight of the regulatory cost</td>
<td>0.04</td>
</tr>
<tr>
<td>$\gamma_b$</td>
<td>The regulatory cost function</td>
<td>0.0013</td>
</tr>
<tr>
<td>$\xi_b$</td>
<td>The regulatory cost function</td>
<td>1</td>
</tr>
<tr>
<td>$\nu^b$</td>
<td>The regulatory capital to total assets ratio</td>
<td>0.045</td>
</tr>
<tr>
<td>$\kappa_d$</td>
<td>Savers’deposits interest rate adjustment cost</td>
<td>70</td>
</tr>
<tr>
<td>$\nu_d$</td>
<td>$\frac{\nu_d}{\nu_d - 1}$ is the mark-down on deposit rate</td>
<td>-8</td>
</tr>
<tr>
<td>$\kappa_{lh}$</td>
<td>Households loan interest rate adjustment cost</td>
<td>20</td>
</tr>
<tr>
<td>$\nu_{L,h}$</td>
<td>$\frac{\nu_{L,h}}{\nu_{L,h} - 1}$ is the mark-up on impatient households loan rate</td>
<td>3.2</td>
</tr>
<tr>
<td>$\kappa_{le}$</td>
<td>entrepreneur loan interest rate adjustment cost</td>
<td>10</td>
</tr>
<tr>
<td>$\nu_{L,e}$</td>
<td>$\frac{\nu_{L,e}}{\nu_{L,e} - 1}$ is the mark-up on entrepreneur loan rate</td>
<td>3.7</td>
</tr>
<tr>
<td>$\rho_R$</td>
<td>Policy rate persistency</td>
<td>0.8</td>
</tr>
<tr>
<td>$r_{pi}$</td>
<td>Taylor rule coefficient on inflation</td>
<td>2</td>
</tr>
<tr>
<td>$r_{\Delta Y}$</td>
<td>Taylor rule coefficient on output growth</td>
<td>0</td>
</tr>
<tr>
<td>$\bar{R}$</td>
<td>Steady-state value of nominal policy rate</td>
<td>0.0075</td>
</tr>
<tr>
<td>$\pi$</td>
<td>Target value of Inflation rate</td>
<td>0.005</td>
</tr>
<tr>
<td>$\sigma^2$</td>
<td>The steady state value of the stochastic policy rate volatility</td>
<td>0.00125</td>
</tr>
<tr>
<td>$\sigma^2_\epsilon$</td>
<td>The steady state value of the stochastic policy rate volatility</td>
<td>0.00125</td>
</tr>
<tr>
<td>$\rho_\sigma$</td>
<td>The AR coefficient of the stochastic policy rate volatility</td>
<td>0.95</td>
</tr>
<tr>
<td>$\eta^\sigma$</td>
<td>The standard deviation of log($\sigma^2_\epsilon$)</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 3: Calibration
Figure 1: Conditional standard deviations and correlation from the BEKK model
Figure 2: IRFs after a 50 bp rise in the monetary policy shock
All rates are shown as absolute deviations from steady state, expressed in percentage points. All other variables are percentage deviations from steady state.
Figure 3: **IRFs after a rise in interbank rate volatility**

All rates are shown as absolute deviations from steady state, expressed in percentage points. All other variables are percentage deviations from steady state.
Figure 4: The transmission of monetary policy in time of interbank rate volatility
All rates are shown as absolute deviations from steady state, expressed in percentage points. All other variables are percentage deviations from steady state.
Figure 5: The impact of the Taylor rule coefficient on inflation $r_x$
Figure 6: The impact of the Taylor rule coefficient on output growth $r_{\delta Y}$
Figure 7: The impact of the persistence in the policy rate $\rho_R$
Appendix: The upward pricing bias and The Rigidity à la Rotemberg

In the paper, we noticed that a volatility shock induce an upward pressure on prices in all the markets provided that they are set by optimizing agents. Thus, even the deposit branch who choose the level of the interest rate they will remunerate with the depositors increases its deposit rate when facing higher uncertainty on its selling interest rate. As it has been assessed by Fernández-Villaverde et al. (2012), this upward pressure is due to the presence of nominal rigidities. However, in this section, we show that this upward pressure is not systematic and has more to do with nominal rigidities specification than the nominal rigidities themselves.

For this purpose, we developed a partial equilibrium model with a banking system à la Gerali et al. (i.e. with the 3 branches) but where we shut down the regulatory constraint, all the remaining variables being exogenous except the interest rates (both lending rates and deposit rate\(^{13}\)). By doing so, we are able to disentangle the pure volatility shock from any other noisy effects such as the general equilibrium effect or the volume one. Fig. 8 shows the results of a 2 std volatility shock on the bank rates.

![Figure 8: IRFs after a 2 std volatility shock - baseline calibration](image)

\(^{13}\)We keep the same calibration than the baseline one.
This figure confirms the fact that the volatility shock has in this model an upward pressure on all the interest rates when the corresponding volumes do not move. As it has been suggested above, the intuition behind this result is as follows. In the optimizing agent point of view, a higher volatility is able to come with a high level of its marginal cost (or its selling price) which means also that he will, in this case, have to adjust its price at a level far from what it is set at the current period. In absence of adjustment costs, this will no reaction from the optimizing agent since he will set its price at the optimal one in each period and with no constraint. However, in the presence of adjustment costs, the optimizing agent knows that in the case he will have to reach a new optimal price, he will face costs that will force him to do it gradually and (probably) in many periods. In consequence and in order to avoid high adjustment costs, the optimizing agent will react in a way that it will minimize a potential cost that he would have to bear. Still, as the adjustment costs are proportional to the (squared) prices growth rates, the best way to minimize future potential costs is to be at a high starting point. This is especially the case when the processus needs different periods to be achieved, indeed with a same adjustment cost the price would be closer to the optimal one when we start from a high starting point than from a lower one. Thus, in order to minimize this future potential costs, optimizing agents will rise their prices, would them be selling price or marginal costs. The key point is that they are the prices involved in the adjustments costs.

In this section, we implement the same partial equilibrium model than above but we change the adjustment costs specification in a way that makes them more sensitive to the inverse growth rates than to the growth rates. The adjustment costs relative to interest rates $R^x$ will be of the form:

$$\frac{\kappa}{2} \left( \frac{R^x_t}{R^x_{t-1}} - 1 \right)^2$$

In this case, more the prices growth rate is high, lower the costs are. We would in consequence expect that the optimizing agent would rather prefer to decrease their prices after a volatility shock. Fig. 9 shows the results of such a specification that confirm our intuition.

The last simulation consists in making the adjustment costs no more sensitive to growth rates and than to the starting point. In this case, we would expect that the optimizing agent would not move its prices. For this purpose, we consider the following adjustment costs:

$$\frac{\kappa}{2} \left( \frac{R^x_t}{R^x_{t-1}} - 1 \right)^2$$

Fig. 10 below represents the results of a such specification that confirm our intuition.
Figure 9: IRFs after a 2 std volatility shock - inverse growth rate
Figure 10: IRFs after a 2 std volatility shock - no growth rate