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Tobias Sebastian Blattner,
Jonathan M. Swarbrick

Monetary policy and cross-border interbank market fragmentation: lessons from the crisis

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Abstract

We present a two-country model with an enhanced banking sector featuring risky lending and cross-border interbank market frictions. We find that (i) the strength of the financial accelerator, when applied to banks operating under uncertainty in an interbank market, will critically depend on the economic and financial structure of the economy; (ii) adverse shocks to the real economy can be the source of banking crisis, causing an increase in interbank funding costs, aggravating the initial shock; and (iii) central bank asset purchases and long-term refinancing operations can be effective substitutes for, or supplements to, conventional monetary policy.

JEL: E44, E52, F32, F36

Keywords: Interbank market, monetary union, financial frictions, cross-border capital flows, unconventional monetary policy.

Non-technical summary

The interbank market plays a pivotal role in the euro area. It is an important source of short-term funding for banks and the first stage of transmission of the ECB's monetary policy to the real economy. Measurable deviations in interbank market funding costs from the ECB's intended policy stance, like in the aftermath of the great financial and euro area sovereign debt crisis, may therefore blur the signal of monetary policy and lead to impairments in the transmission.

This article develops, calibrates and simulates a structural model of the euro area economy that incorporates three major factors, or frictions, that may cause such deviations to emerge: asymmetric information between borrowers and lenders, monitoring costs and counterparty uncertainty. Specifically, we assume that there are two countries and two types of banks in each country: savings banks, which have excess liquidity that they are willing to trade across borders in the interbank market, and lending banks, which operate under a structural liquidity deficit and require funding that they can obtain from the unsecured area-wide interbank market. Lending banks, however, face idiosyncratic loan return shocks that are unobservable from the point of view of savings banks. These shocks mean that lending banks have a positive probability of default, which gives rise to a spread over the risk-free rate controlled by the central bank. In addition, lending banks face an additional risk premium when taking a position in the cross-border interbank market, where asymmetric information, counterparty risk and search and monitoring costs are particularly relevant.

Our key findings are that such frictions in the interbank market can play an important role in propagating and amplifying the effects of both idiosyncratic and common shocks in a currency union. For example, adverse shocks hitting both countries equally will cause lending banks to raise the risk premium they charge in the interbank market, thereby driving a wedge between banks' funding costs and the key policy rate controlled by the monetary authority. This wedge will be even wider for cross-border interbank trades, thereby hitting countries with a greater reliance on international wholesale funding more strongly.

While such interbank market frictions can therefore reduce the effectiveness of conventional monetary policy actions, our simulations also show that non-standard policy

measures, such as central bank asset purchases or long-term refinancing operations, can effectively restore the orderly transmission of monetary policy by either freeing up bank balance sheet capacity or by frontloading required monetary accommodation. Such measures can therefore complement, or substitute for, changes in the key policy rate and ease financial conditions at a time when access to interbank credit might be restricted or excessively expensive.

1 Introduction

In the years following the global financial and the euro area sovereign debt crisis, the process of financial integration in the euro area moved into reverse as firms and households in the southern European periphery started to face much higher borrowing costs than their counterparts in the northern core. One of the key channels at the heart of this financial fragmentation was the interbank market where the costs of cross-border lending rose sharply, and volumes fell dramatically, in particular in peripheral economies, thereby likely having contributed to reinforcing the macroeconomic fallout from the sharp collapse in aggregate demand. Although market segregation gradually receded over the past few years, probably also thanks to the actions taken by the European Central Bank (ECB), normal market functioning has not yet been fully restored. At face value, these facts contradict the predictions of standard open-economy models in which complete financial markets can be expected to facilitate, rather than to impede, effective risk-sharing and thereby help temper the adverse effects of asymmetric shocks.

Against this background, and with a view to improving our understanding of recent events, this article analyses the role of frictions in the interbank market of a currency union and examines how unconventional monetary policy measures may mitigate, or offset, the effects such frictions may have on financial conditions and, ultimately, on output and inflation. To this aim, we develop, calibrate and simulate a two-country dynamic stochastic general equilibrium (DSGE) model in which lending banks obtain funds from both domestic and foreign savings banks to refinance loans to the private sector, but where interbank lending is subject to both borrower and country-specific idiosyncratic risk. Using this framework, we show that (i) the strength of the financial accelerator, when applied to banks operating under uncertainty in an interbank market, will critically depend on the economic and financial structure of the economy; (ii) adverse shocks to the real economy can be the source of banking crises, causing an increase in the interbank fundig costs, aggravating the initial shock; and (iii) central bank asset purchase policies and long-term refinancing operations can both be an effective substitute for, or complement to, changes in the conventional monetary policy instrument.

The interbank market plays a pivotal role in the euro area. Its smooth functioning is central for banks to cope efficiently with idiosyncratic liquidity shocks and to ensure a uniform transmission of the common monetary policy. Frictions in the interbank

market may blur the signal coming from monetary policy and ultimately hamper its transmission. One reason why interbank markets may not operate efficiently has to do with transaction costs: owing to the unsecured lending nature of the market, and its over-the-counter (OTC) structure[1], trading relationships are often plagued by asymmetric information, counterparty risk and search and monitoring costs (see e.g. Afonso et al. 2011, Flannery 1996). As a result, banks' wholesale market funding costs may differ across the currency union, and some banks may face hard borrowing constraints, which could affect both credit supply and the ultimate borrowing conditions of the non-financial sector.

These frictions are particularly relevant in cross-border transactions, where differences in banking supervision up until the introduction of the Single Supervisory Mechanism (SSM) in 2014,[2] the state of the business cycle, insolvency laws or accounting standards may obfuscate the evaluation of the creditworthiness of foreign banks and expose lenders to uncertain counterparty risk. Freixas and Holthausen (2005) show that such market imperfections may cause liquidity shortages or the payment of interest rate premia that reflect the adverse selection of borrowers across countries. In crisis times, these effects may become even more visible. Using bank-to-bank loan level data from TARGET2[3], Abbassi et al. (2014) find that for the same borrower on the same trading day, and after controlling for lender and borrower fixed effects, cross-border loans were up to 25 basis points more expensive than domestic loans in the first three months following the collapse of the former investment bank Lehman Brothers in 2008. De Andoain et al. (2014) estimate that the premium charged to banks in more stressed economies spiked even more dramatically, reaching over 63 basis points. The presence of a risk premia unrelated to the specific borrower suggests that information asymmetry constraints are important and that factors other than direct counterparty risks may also drive pricing behavior in interbank markets.

Cross-border interbank lending has been and continues to be an important element of the financial structure in the euro area. Prior to the outbreak of the global financial

[1]Electronic trading accounted for less than 10% of total unsecured transactions in 2014 (ECB 2015).

[2]Even after the introduction of the SSM, national competent authorities retain discretion in applying common rules (see Nouy 2017).

[3]TARGET2 is the Eurosystem's payment and settlement system and carries out more than 90% of all fund flows between pairs of credit institutions in the euro area.

crisis, more than half of the average daily turnover in the unsecured market was with non-domestic euro area counterparts (ECB 2009*a*). Strong credit growth in parts of the euro area, buoyant financial innovation and lax financial regulation all contributed to an increasing reliance on confidence-sensitive wholesale funding, with banks in current account surplus countries providing funding to banks in current account deficit countries (see van Rixtel and Gasperini 2013). After the outbreak of the crisis, the share of cross-border interbank lending fell dramatically to just over 25% in 2013 before recovering again to reach levels around 40% in 2014 (ECB 2015).

These sharp variations in the funding structure of banks – broadly speaking the mix between wholesale and deposit funding – may have had severe repercussions on their operations and their willingness and ability to extend credit to the non-financial sector. Several empirical studies document that banks whose liabilities are mainly sticky household deposits, which are often protected by generous government insurance schemes, continued to lend in the aftermath of the crisis whereas banks that relied predominantly on debt funding fared worse (Cornett et al. 2011, Ivashina and Scharfstein 2010, Demirgüç-Kunt and Huizinga 2010). In other words, wholesale funding, and cross-border funding in particular, makes banks more vulnerable to changes in market financing conditions with possibly strong repercussion on bank lending. These studies therefore tend to suggest that real shocks may be amplified, and financial shocks accelerated, by banks' structural recourse to wholesale financing.

Despite its empirical relevance, however, few efforts have been undertaken to study the main mechanisms and propagation channels of the interbank market in a structural model of the macroeconomy. Indeed, financing frictions were long absent in a general equilibrium context. The dominance of the Modigliani-Miller theorem (1958) that the financing structure of a firm is irrelevant for its value confined the analysis to real and nominal frictions in the wider economy (Christiano et al. 2005, Smets and Wouters 2007). The seminal work by Bernanke et al. (1999) and the subsequent contributions by Christiano et al. (2004, 2010, 2014) and Iacoviello (2005) made financial factors acceptable, and even desirable, in workhorse general equilibrium models. Their studies showed that asymmetric information, agency problems and borrowing constraints are important factors in driving and amplifying business cycles.

Yet, less progress has been made in understanding the impact of the financing structure

of banks on lending conditions of the private sector and, hence, on aggregate output and inflation. In the pioneering work of Bernanke et al. (1999) and Christiano et al. (2004), and in subsequent work that followed (cf. Goodfriend and Mccallum 2007, De Graeve 2008, Christensen and Dib 2008), banks were either relegated to act as simple intermediaries between savers and borrowers or were operating under perfect competition.

It was only more recently that a more prominent role was given to banks in general equilibrium models. Gerali et al. (2010) and Darracq Paries et al. (2011) illustrate the effects of imperfect competition in the banking industry on credit spreads and show that changes in banks' leverage ratio can impact loan supply conditions. However, in these models, banks can obtain funding in a frictionless interbank market at the rate set by the central bank. Others have made attempts to model the interbank market more explicitly. Gertler and Kiyotaki (2010), building on Kiyotaki and Moore (1997), introduce a borrowing constraint in the interbank market by assuming that banks may divert borrowed assets for personal gain, causing a spread between lending and deposit rates. In the face of an adverse shock, this spread widens, which raises the cost of credit of firms, affecting real activity.

Dib (2010) and de Walque et al. (2010) include an interbank market in which, due to an implicit enforceability problem, borrowing banks can choose an optimal level of default,[4] and where banks must hold a regulatory level of capital. Calibrated for the US economy, both papers show that bank capital attenuates, rather than amplifies, the real effects of shocks in this framework. Hilberg and Hollmayr (2011) incorporate a secured interbank market into an otherwise standard DSGE model and study the impact of central bank collateral policy on interbank lending rates. They show that a change in the haircut applied to central bank refinancing operations can be effective in steering interbank rates, but that the presence of an interbank market also attenuates the effects of conventional monetary policy. Similarly, Carrera and Vega (2012) model the interactions between banks' reserve requirements and interbank lending activity, which they assume is costly due to monitoring costs. They find that an increase in required reserves increases demand in the competitive interbank market and pushes up the interest rate charged on these operations as lending banks will have to pay higher monitoring costs. Funding conditions in the interbank market then trickle down to lending and deposit rates, affecting real

[4] That is, default is not related to banks' own idiosyncratic risks but a choice variable subject to an exogenous cost of default.

activity. In the framework of Carrera and Vega (2012), changes in reserve requirements are therefore qualitatively similar to traditional changes in policy rates.

Cross-border interbank lending, by contrast, has been largely ignored so far in the literature. In 't Veld and van Lelyveld (2014) examine the role of international capital flows in the boom-bust cycle in Spain by allowing borrowing-constrained households to borrow directly from foreign lenders. Using an estimated three-country model, they find that the convergence of interest rates in Spain to the levels prevailing in other euro area Member States, a loosening of collateral constraints as well as falling risk premia on Spanish housing and capital has fuelled the Spanish housing boom. Poutineau and Vermandel (2015) model the banking sector explicitly in a two-country DSGE model. Contrary to Quint and Rabanal (2014), who study the optimal design of macro-prudential policies in the euro area in a two-country DSGE model, they allow for cross-border lending to firms and banks. They find that cross-border loans amplify the propagation of country-specific shocks. Dräger and Proaño (2015) also allow for cross-border banking where an international wholesale branch is collecting deposits from across the currency union and distributes them to retail banks in the two countries. Although their model gives not rise to interbank flows, similar to Poutineau and Vermandel (2015), they find that cross-border banking amplifies the effects of exogenous shocks in a currency union.

In this article, we try to bring the various strands of the literature together by incorporating credit risk in the interbank market of a currency union in a New Keynesian two-country, two-sector model with sticky prices, habits in consumption and investment adjustment costs. There are two types of banks in each country: savings banks, which have excess liquidity that they are willing to trade across borders in the interbank market, and lending banks, which operate under a structural liquidity deficit and require funding that they can obtain from the unsecured area-wide interbank market. Following the costly state verification framework of Bernanke et al. (1999), lending banks face idiosyncratic loan return shocks that are unobservable from the point of view of savings banks. A positive probability of default gives rise to an external finance premium that depends on the leverage of the borrower.

In addition, lending banks face a risk premium when taking a position in the cross-border interbank market. This second friction is in the same spirit as the external financial intermediation premium in Christoffel et al. (2008), but tailored to the features

of an interbank market: as lending banks' domestic economy's net foreign asset position weakens, or when the risk in the domestic economy increases, foreign lenders demand a higher rate of interest vis-à-vis the borrower from that country as counterparty risk rises, thereby driving a further wedge between the policy rate and interbank lending rates.

We use our model to answer three important questions: (1) how is the transmission of monetary policy in a currency union affected when financing conditions in the interbank market depend on the quality of banks' balance sheets; (2) how do asymmetric shocks to the value of assets propagate through a currency union when savings banks differentiate between domestic and foreign borrowers in the interbank market; and (3) how effective are some of the measures central banks have taken in the recent past to address funding bottlenecks in the interbank market?

Regarding the first question, we find that our model exhibits the financial accelerator effect (see Bernanke et al. 1999) in the face of a common monetary policy shock but that, compared to previous findings in the literature, there are noticeable differences in the way our model can give rise to changes in the transmission of monetary policy. In particular, compared to a situation where the financial accelerator operates directly at the balance sheet of firms, the strength, and at times also the direction of propagation, crucially depends on the share of saver households in the economy, the asset composition of lending banks' balance sheets and the degree of competition in the lending market.

Regarding the second question, our model is able to replicate some of the key features of the financial crisis that resulted in a segmented interbank market.[5] We show that capital flows resulting from international financial integration can be highly procyclical, fluctuating in response to business cycles, thereby raising financial and economic fragility even before a crisis emerges, mainly by fostering credit growth. This means that in the wake of an adverse shock to the value of assets in one country, the rate charged by foreign lenders in the common interbank market will rise as banks' balance sheets deteriorate amid a fall in the collateral value. The increase in the interbank funding cost of banks in this economy offsets, to some extent, the effort by the central bank to stimulate the

[5] In our model we focus on loan return risk. Ultimately, the implications of our findings are more broad-based and less dependent on the ultimate source of risk. For example, the sharp increase in spreads paid by banks in stressed Member States during the sovereign debt crisis (see e.g De Andoain et al. 2014) works through the same channel, that is, a (perceived) deterioration in the quality of banks' balance sheets.

(area-wide) economy by lowering the policy rate in response to the initial shock. That is, compared to a model without cross-border interbank lending, and contrary to union-wide shocks, monetary policy will be less effective. Moreover, as foreign funding becomes more expensive, the economy that draws the shock is forced to improve its trade balance more sharply relative to the case without financial frictions.

Finally, we study the effectiveness of two of the ECB's recent non-standard measures. We find that providing long-term refinancing operations (LTROs) to banks increases the effectiveness of monetary policy per unit of stimulus – that is, LTROs empower conventional monetary policy. The second policy focuses on the ECB's asset-backed securities purchase programme (ABSPP) that is particularly well suited to study in our model economy. Although securitization is more complex in practice, the ultimate effects of the ABSPP can be well approximated by assuming that the central banks purchases directly risky loans from banks, thereby freeing up bank balance sheet capacity and reducing their funding costs in the interbank market. We find that asset purchases in the form of loans, either directly or through purchases of ABS, can be an effective substitute for, or complement to, reductions in the key policy rate.

The rest of the paper is organized as follows. Section 2 lays out the model setup. Section 3 discusses model calibration and section 4 presents numerical simulations, illustrating the role of the interbank market in driving the dynamics of the model. Section 5 analyses the effects of the ECB's policy measures, while section 6 offers some concluding remarks.

2 The Model

The model is made up of two economies that share a single currency and monetary policy. In each economy there are two types of households, savers and borrowers, monopolistic competitive firms, savings and lending banks as well as a fiscal authority. The two economies, of size n and $(1-n)$, trade in both non-durable consumption goods and financial services in the form of interbank credit. In the following, we describe the decision-making problems of the economic agents resident in the home economy. Unless otherwise stated, analogous conditions hold for the foreign economy. The time notation refers to the period in which the value is determined.

2.1 Households

The household sector is made up of a mass $\lambda \in [0,1]$ of patient households with discount factor β and $(1-\lambda)$ of impatient households with discount factor $\beta^B < \beta$. The patient households are referred to as the *savers* and the impatient households as the *borrowers*.

2.1.1 Savers

The saver household $h \in [0,\lambda]$ chooses the level of consumption of non-durable goods $C_{h,t}$, hours worked $L_{h,t}$, the housing stock $D_{h,t}$, and bank deposit savings $S_{h,t}$ to maximize its lifetime utility

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left\{ \varrho \ln\left(C_{h,t+s} - \kappa C_{t+s-1}\right) + (1-\varrho)\ln(D_{h,t+s-1}) - \frac{L_{h,t+s}^{1+\phi}}{1+\phi} \right\}$$

subject to the nominal budget constraint

$$P_t^C C_{h,t} + P_t^D \left(D_{h,t} - (1-\delta_D) D_{h,t-1}\right) + S_{h,t} \leq R_{t-1}^S S_{h,t-1} + W_t L_{h,t} + \pi_t - T_t$$

where ϱ determines the relative weight of non-durable consumption in the saver's utility and κ the degree of external habit formation in consumption. The parameter ϕ refers to the inverse of the Frisch labour supply elasticity. P_t^C and P_t^D are the price indices for consumption and housing goods respectively (see derivation below). $\delta_D \in (0,1)$ denotes the depreciation rate of housing. The saver can deposit his savings in domestic banks which pay the risk-free nominal interest rate R_t^S. Finally, the saver provides labour at the flexible nominal wage rate W_t and owns the stock of net wealth of the economy, except for housing that is in part also owned by the borrower household, therefore receiving profits π_t from the banking and corporate sector and paying lump sum taxes T_t.

Because saver households have the same preferences over consumption, housing, labour, savings and investment, and are assumed to have the same initial wealth, we focus on a representative saver from now onwards and drop the h subscript. The saver household chooses the optimal inter-temporal plan subject to the budget constraint, resulting in a

set of familiar first-order conditions that will hold in equilibrium:

$$1 = R_t^S \mathbb{E}_t \left[\frac{\Lambda_{t,t+1}}{\Pi_{t+1}^C} \right] \tag{2.1}$$

$$\lambda_t^C Q_t^D = \beta \mathbb{E}_t \left[\lambda_{t+1}^D + (1-\delta_D) Q_{t+1}^D \lambda_{t+1}^C \right] \tag{2.2}$$

$$w_t = \frac{L_t^\phi}{\lambda_t^C}, \tag{2.3}$$

where λ_t^C and λ_t^D are the marginal utilities of consumption and housing respectively, and $\Lambda_{t,t+1} \equiv \beta \frac{\lambda_{t+1}^C}{\lambda_t^C}$ is the real stochastic discount factor over the interval $[t, t+1]$. Equations (2.1) and (2.2) are the Euler equations implied by the demand for domestic deposits and the demand for housing respectively. The relative price of housing is given by $Q_t^D \equiv \frac{P_t^D}{P_t^C}$ and inflation is defined by $\Pi_t^C \equiv P_t^C / P_{t-1}^C$. The real wage rate is given by $w_t = W_t / P_t^C$, which is equal to the marginal rate of substitution between labour and consumption in equilibrium (2.3).

2.1.2 Borrowers

Preferences of the borrowers are the same as those of the saver except for the difference in the time discounting. Borrower household $h \in [\lambda, 1]$ maximizes

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta_B^s \left\{ \varrho \ln(C_{h,t+s}^B - \kappa C_{t+s-1}^B) + (1-\varrho) \ln(D_{h,t+s-1}^B) - \frac{(L_{h,t+s}^B)^{1+\phi}}{1+\phi} \right\},$$

subject to the nominal budget constraint

$$P_t^C C_{h,t}^B + P_t^D \left(D_{h,t}^B - (1-\delta_D) D_{h,t-1}^B \right) + R_{h,t-1}^M C R_{h,t-1}^{HH} \leq C R_{h,t}^{HH} + W_t L_{h,t}^B.$$

The notations are identical to the saver household and where the superscript B characterizes variables specific to borrowers. As in Kiyotaki and Moore (1997) and Iacoviello (2005), borrowers finance their consumption of housing with credit $CR_{h,t}^{HH}$ obtained from lending banks at the mortgage rate $R_{h,t}^M$. Banks impose collateral constraints of the form

$$C R_{h,t}^{HH} \leq m P_t^D D_{h,t}^B.$$

That is, banks will only lend out a fraction m of the housing value with a view to ensuring that households will not default the following period. For numerical simplicity, we assume that the borrowing constraint is always binding. While this will certainly be

true in the deterministic steady state, under uncertainty the borrowers could self-insure in some states of the world by borrowing below the limit to protect against the effects of adverse shocks. We therefore follow Iacoviello (2005) and choose the parameter m to minimize the probability of this occurring.

The decision-making problems of the representative borrower household lead to a labour supply condition analogous to that of the saver household. The housing investment decision leads to an Euler equation of the form

$$\mathbb{E}_t \left[\beta \frac{\lambda_{t+1}^{D,B}}{\lambda_t^{C,B}} \frac{P_t^C}{P_t^D} + \frac{\Lambda_{t,t+1}^B}{\Pi_{t,t+1}} \left(\Pi_{t,t+1}^D \left(1 - \delta_D\right) - R_{h,t}^M m \right) \right] = 1 - m. \tag{2.4}$$

2.2 Firms

We introduce nominal rigidities in the price of consumption goods following Calvo (1983). To this end, we assume there are two types of firms in the model economy: intermediate goods firms that are price takers in perfect competition, and final goods firms that operate under monopolistic competition. There is 'price-stickiness' introduced in the latter sector as only a fixed proportion of firms is able to update prices each period.

2.2.1 Intermediate goods firms

Each intermediate goods producer hires capital services K_t^D and labour L_t^D to produce a homogeneous output $Y_{w,t}$ subject to a Cobb-Douglas production function

$$Y_{w,t} = A_t Z_t (K_t^D)^{\alpha} (L_t^D)^{1-\alpha}$$

where the superscript D indicates factor demand, and A_t and Z_t are, respectively, stationary union-wide and country-specific total factor productivity shocks. Both are modelled as AR(1) processes: $a_t^A = \rho^A a_{t-1}^A + \varepsilon_t^A$ where $a_t \equiv \ln A_t$ and with a normal i.i.d. shock ε_t^A. There is an equivalent process for $z_t \equiv \ln Z_t$. Taking both the aggregate real wage index w_t and real rental price of capital r_t^k as given, the profit maximization implies labour and capital demand given by

$$w_t = \alpha \frac{P_{w,t}}{P_t^C} \frac{Y_{w,t}}{L_t^D} \tag{2.5}$$

$$r_t^k = (1 - \alpha) \frac{P_{w,t}}{P_t^C} \frac{Y_{w,t}}{K_t^D} \tag{2.6}$$

where $P_{w,t}$ is the price at which the output is sold to all final goods firms. This implies that $P_{w,t}/P_t^C = mc_t$ is the real marginal cost in the final good sector.

2.2.2 Final Good Producers

Each final good producer firm j purchases output from the intermediate good sector at price $P_{w,t}$ and converts it into a differentiated good sold at price $P_t^P(j)$ to households, durable good producers and the fiscal authority. Summing the demand schedules from each buyer (see Section 2.2.3) implies a total demand for good j given by

$$Y_t(j) = \left(\frac{P_t^P(j)}{P_t^P}\right)^{-\sigma} Y_t.$$

where σ denotes the elasticity of substitution between the different varieties, assumed to be identical across the currency union. Every period, each firm faces a fixed probability $1-\xi$ that it will be able to update its price. Denoting the optimal price at time t for good j as $P_t^*(j)$, the firms allowed to re-optimize prices maximize expected discounted profits by solving

$$\max_{P_t^*(j)} \mathbb{E}_t \sum_{k=0}^{\infty} \xi^k \frac{\Lambda_{t,t+k}}{P_{t+k}^C} Y_{t+k}(j) \left[P_t^*(j) - P_{w,t+k}\right].$$

The solution to the price setting problem yields a price P_t^* which is independent of the firm's history of prices and therefore optimal for all price setters. With real marginal cost given by $mc_t = \frac{P_{w,t}}{P_t^C}$ and producer price inflation denoted by $\Pi_t^P \equiv \frac{P_t^P}{P_{t-1}^P}$, we can write this as

$$\frac{P_t^*}{P_t^P} = \frac{\sigma}{\sigma-1} \frac{\mathbb{E}_t \sum_{k=0}^{\infty} \xi^k \Lambda_{t,t+k} \left(\Pi_{t,t+k}^P\right)^{\sigma} Y_{t+k} mc_{t+k}}{\frac{P_t^P}{P_t^C} \mathbb{E}_t \sum_{k=0}^{\infty} \xi^k \Lambda_{t,t+k} \left(\Pi_{t,t+k}^P\right)^{\sigma} \left(\Pi_{t,t+k}^C\right)^{-1} Y_{t+k}}.$$

Using the aggregate producer price index P_t^P and the fact that all resetting firms will choose the same price, by the law of large numbers we can find the evolution of the price index as given by

$$\left(P_t^P\right)^{1-\sigma} = \xi \left(P_{t-1}^P\right)^{1-\sigma} + (1-\xi)\left(P_t^*\right)^{1-\sigma}. \tag{2.7}$$

Whilst the distribution of prices is not required to track the evolution of the aggregate price index, it implies a loss of output due to dispersion in prices. Final output is given

by $Y_t = Y_{w,t}\frac{1}{\Delta_t}$ where price dispersion is given by

$$\Delta_t = \frac{1}{J}\sum_{j-1}^{J}\left(\frac{P_t^P(j)}{P_t^P}\right)^{-\sigma}$$

for non-optimizing firms $j = 1, ..., J$. As a proportion $(1-\xi)$ of firms will optimize prices in period t and knowing that the distribution of non-optimized prices will be the same as the overall distribution, price dispersion can be written as a law of motion

$$\Delta_t = \xi\Pi_t^{\sigma}\Delta_{t-1} + (1-\xi)\left(\frac{\Omega_{1,t}}{\Omega_{2,t}}\right)^{-\sigma}. \tag{2.8}$$

2.2.3 Consumption Good Producers

Households purchase differentiated final goods and combine bundles of domestically produced goods and aggregate imports to produce the final consumption bundle according to

$$C_t = \left[\left(\tau^C\right)^{\frac{1}{\theta_C}} H_t^{\frac{\theta_C-1}{\theta_C}} + \left(1-\tau^C\right)^{\frac{1}{\theta_C}} IM_t^{\frac{\theta_C-1}{\theta_C}}\right]^{\frac{\theta_C}{\theta_C-1}}$$

where τ^C can be interpreted as the degree of home bias in household consumption expenditures, and θ_C is the CES between domestic and foreign produced goods (see Armington 1969). H_t and IM_t are bundles of differentiated domestic and foreign produced goods which households combine into baskets of goods using

$$H_t = \left(\int_0^1 H_t(j)^{\frac{\sigma-1}{\sigma}}\mathrm{d}j\right)^{\frac{\sigma}{\sigma-1}} \tag{2.9}$$

$$IM_t = \left(\int_0^1 IM_t(j^*)^{\frac{\sigma-1}{\sigma}}\mathrm{d}j^*\right)^{\frac{\sigma}{\sigma-1}} \tag{2.10}$$

where the asterisk indicates variables of the foreign country. The households purchase good $H_t(j)$ from producer $j \in (0,1)$ at price $P_t^P(j)$ to maximize (2.9) subject to total expenditure $P_t^P H_t = \int_0^1 P_t^P(j)H_t(j)\mathrm{d}j$, with an equivalent problem for imports $IM_t(j^*)$. This leads to Dixit and Stiglitz (1977) demand schedules

$$H_t(j) = \left(\frac{P_t^P(j)}{P_t^P}\right)^{-\sigma} H_t \tag{2.11}$$

$$IM_t(j^*) = \left(\frac{P_t^{IM}(j^*)}{P_t^{IM}}\right)^{-\sigma} IM_t. \tag{2.12}$$

Equivalent conditions for the domestic demand of the investment good and government consumption good hold. We assume no pricing to market, which implies that $P_t^{IM} = P_t^{P^*}$. The final good firms take input prices as given and maximize their profits $P_t^C C_t - P_t^P H_t - P_t^{IM} IM_t$. Profit maximization yields the following demand schedules for the domestic bundle and aggregate imports

$$H_t = \tau^C \left(\frac{P_t^P}{P_t^C}\right)^{-\theta_C} C_t \tag{2.13}$$

$$IM_t = (1-\tau^C) \left(\frac{P_t^{IM}}{P_t^C}\right)^{-\theta_C} C_t \tag{2.14}$$

This leads to the consumer price index P_t^C given by

$$P_t^C = \left[\tau^C \left(P_t^P\right)^{1-\theta_C} + (1-\tau^C)\left(P_t^{IM}\right)^{1-\theta_C}\right]^{\frac{1}{1-\theta_C}}. \tag{2.15}$$

2.2.4 Housing Producers

The price of durable housing goods can differ from that of consumption goods due to the presence of adjustment costs. To ensure that savers and borrowers observe the same house price, we let housing good producers augment the existing stock D_t^T according to the following law of motion

$$D_t^T = (1-\delta_D) D_{t-1}^T + \left[1 - S\left(\frac{I_t^D}{I_{t-1}^D}\right)\right] I_t^D \tag{2.16}$$

where the function $S(\cdot)$ is a positive function of changes to investment, as applied to capital formation in Christiano et al. (2005), and is given by

$$S\left(\frac{I_t^D}{I_{t-1}^D}\right) = \frac{\zeta^D}{2}\left(\frac{I_t^D}{I_{t-1}^D} - 1\right)^2. \tag{2.17}$$

The housing goods producers solve

$$\max_{I_t^D} \mathbb{E}_t \sum_{s=0}^{\infty} \frac{\Lambda_{t,t+s}}{P_{t+s}^C}\left(P_{t+s}^D \left[1 - S\left(\frac{I_{t+s}^D}{I_{t-1+s}^D}\right)\right] I_{t+s}^D - P_{t+s}^P I_{t+s}^D\right),$$

where P_t^P is the domestic producer price. This leads to the first-order condition

$$\frac{P_t^P}{P_t^C} = Q_t^D \left(1 - \frac{\zeta^D}{2}\left(\frac{I_t^D}{I_{t-1}^D} - 1\right)^2 - \zeta^D \left(\frac{I_t^D}{I_{t-1}^D} - 1\right)\frac{I_t^D}{I_{t-1}^D}\right) + \mathbb{E}_t\left[\Lambda_{t,t+1} Q_{t+1}^D \zeta^D \left(\frac{I_{t+1}^D}{I_t^D} - 1\right)\left(\frac{I_{t+1}^D}{I_t^D}\right)^2\right]. \quad (2.18)$$

2.3 Financial Intermediation

There are two types of banks: savings banks that take deposits from domestic households and lend in the currency union-wide interbank market and lending banks that provide loans to both domestic firms and households and finance these using interbank borrowing and their own net worth. A financial friction emerges due to idiosyncratic loan return shocks faced by lending banks. Costly state verification leads to an external finance premium as in Bernanke et al. (1999). In addition, in light of the empirical evidence that borrower banks often have to pay a premium that reflects not borrower but country-specific risks when accessing the international interbank market (cf. Section 1), we add a further friction whereby cross-border interbank credit faces additional monitoring costs that depend on the exposure of the borrowing country to foreign debt and to the prevailing risk in the lending market.

Savings banks operate under perfect competition with free entry, but aggregate shocks can lead to unexpected profits or losses. The banks are owned by the patient households who are paid all bank profits, or recapitalize banks if and when necessary. Lending banks face idiosyncratic shocks when extending credit to the real economy that are costly for creditors to observe. Limited liability implies that these banks earn profits in equilibrium. Lending banks are treated slightly differently to savings banks in that they pay a fixed dividend rate to ensure they cannot become fully self-funded, equivalent to the assumption of an exogenous exit rate or higher banker discounting (see e.g. Bernanke et al. 1999, Gertler and Kiyotaki 2010). The friction implies that equity is always more valuable than debt, without which banks would not pay dividends in equilibrium. Another difference is that savings banks can access central bank credit whereas lending banks cannot. This is in part motivated by the risk exposure and specialization of lending banks; savings banks are well diversified and the central bank requires a proportion of

safe assets as collateral.

2.3.1 Lending Banks

There are many lending banks of unit mass indexed $b \in [0,1]$. They extend credit CR_t to the non-financial sector, which they finance with domestic IB_t^H and cross-border IB_t^F interbank borrowing and net worth N_t:

$$CR_t = N_t + IB_t^H + IB_t^F \tag{2.19}$$

where IB_t^H and IB_t^F are chosen to maximize a CES Armington aggregator (see Armington 1969) of domestic and foreign interbank borrowing

$$IB_t = \left[\left(\tau^{IB}\right)^{\frac{1}{\theta_{IB}}} \left(IB_t^H\right)^{\frac{\theta_{IB}-1}{\theta_{IB}}} + \left(1-\tau^{IB}\right)^{\frac{1}{\theta_{IB}}} \left(IB_t^F\right)^{\frac{\theta_{IB}-1}{\theta_{IB}}} \right]^{\frac{\theta_{IB}}{\theta_{IB}-1}}$$

where τ^{IB} can be interpreted as a home bias in interbank borrowing and θ_{IB} is the elasticity of substitution between domestic and foreign borrowing. A non-zero θ_{IB} implies that domestic and foreign interbank borrowing are not perfect substitutes, rendering differences in lending rates. Maximization yields the following familiar demand schedules

$$IB_t^H = \tau^{IB} \left(\frac{R_t^{IB,H}}{R_t^{IB}} \right)^{-\theta_{IB}} IB_t \tag{2.20}$$

$$IB_t^F = (1-\tau^{IB}) \left(\frac{R_t^{IB,F}}{R_t^{IB}} \right)^{-\theta_{IB}} IB_t \tag{2.21}$$

where $R_t^{IB,H}$ is the lending rate on the domestic interbank market and $R_t^{IB,F}$ the rate on the cross-border market. Using these demand schedules and $R_t^{IB} IB_t = R_t^{IB,H} IB_t^H + R_t^{IB,F} IB_t^F$, composite interbank funding costs are given by

$$R_t^{IB} = \left[\tau^{IB} \left(R_t^{IB,H}\right)^{1-\theta_{IB}} + (1-\tau^{IB}) \left(R_t^{IB,F}\right)^{1-\theta_{IB}} \right]^{\frac{1}{1-\theta_{IB}}}. \tag{2.22}$$

When granting loans to the non-financial private sector, we assume that lending banks cannot diversify risk in their loan portfolio and that they experience idiosyncratic loan return shocks $\omega_t(b)$ that affect the value of the asset side of their balance sheets.[6] The shocks are log-normally distributed, $\log(\omega_t(b)) \sim \mathcal{N}\left(-(\sigma_{\omega,t}^2/2), \sigma_{\omega,t}^2\right)$, with mean

[6] Thus allowing us to study imperfect diversification in a tractable way.

$\mathbb{E}_t[\omega_t] = 1$ and standard deviation $\sigma_{\omega,t}$, which is time-varying and is modelled as an AR(1) process: $\log(\sigma_{\omega,t}) = (1-\rho_\sigma)\log(\sigma_{\omega,ss}) + \rho_\sigma \log(\sigma_{\omega,t-1}) + u_{\omega,t}$ and $u_{\omega,t} \sim \mathcal{N}(0, \sigma_\sigma)$.

After aggregate and idiosyncratic shocks hit the economy, net worth of lending banks evolves according to

$$N_t(b) = \omega_t(b) R_t^{CR} CR_{t-1}(b) - R_{t-1}^{IB} IB_{t-1}(b) \tag{2.23}$$

where R_t^{CR} is the *ex post* return on banks' loan portfolio CR_t. Limited liability implies that if the realization of the shock is below a threshold value $\bar{\omega}_t$, then the lending bank will default on its interbank borrowing as they would otherwise be insolvent. This threshold value is found when setting $N_t(b) = 0$:

$$\bar{\omega}_t(b) = \frac{R_{t-1}^{IB} IB_{t-1}(b)}{R_t^{CR} CR_{t-1}(b)} \tag{2.24}$$

The lending banks will pay the saver households a fixed dividend rate, investing all remaining profits in their own net worth. It is assumed that a defaulting bank will exit but that for every exiting bank, a new one enters and is given a small start-up fund by the other banks. This ensures that the number of banks is held constant at any point in time. The idiosyncratic loan return and default leads to a distribution of lending banks over all possible values of net worth.

The loan portfolio is comprised of mortgage loans to households CR_t^{HH} and lending to firms CR_t^F. The former are treated as nominal one period bonds, whereas, for the latter, it is convenient to consider the banks owning the physical capital directly and renting it out to firms.[7] Capital investment is subject to costs analogous to those in housing investment and, to ensure the leverage of a bank is independent of its net worth, we introduce a representative capital producer that sells capital to the banks at relative price Q_t^K. This leads to a first order condition equivalent to equation (2.18) that determines Q_t^K. Gross nominal return on capital is given by

$$R_t^K = \frac{r_t^K + (1-\delta_K) Q_t^K}{Q_{t-1}^K} \Pi_{t-1,t}. \tag{2.25}$$

The lending banks specify a contract for interbank funds subject to participation constraints given in the following section. After detailing the solution to the savings banks'

[7] As in Gertler and Kiyotaki (2010). This is equivalent to the firms using state-contingent debt to purchase the capital themselves. It is natural to assume that debt contracts are state-contingent due to costless monitoring and enforcement, and the risk neutrality of the lender.

problem, we discuss the contract that determines the demand for interbank credit, and the supply of credit to the non-financial private sector.

2.3.2 Savings Banks

A representative savings bank has access to the central bank's liquidity providing operations CB_t, raises deposits S_t from patient households and extends both domestic IB_t^H and cross-border $IB_t^{F^*}$ interbank loans:

$$S_t + CB_t = IB_t^H + IB_t^{F^*} \tag{2.26}$$

Maximizing the expected profits leads to the zero-arbitrage condition

$$\mathbb{E}_t \left[\frac{\Lambda_{t,t+1}}{P_{t+1}^C} R_t^S \right] = \mathbb{E}_t \left[\frac{\Lambda_{t,t+1}}{P_{t+1}^C} \tilde{R}_{t+1}^{IB} \right]$$

where $\tilde{R}_t^{IB}$ is the *ex post* return on interbank lending, and the condition $R_t^S = R_t$ under standard one-period central bank finance, where R_t is the policy rate. The savings bank can only observe the loan return of the lending bank if it pays a proportional monitoring fee μ. As shown in Townsend (1979), the implication of this costly state verification is that the fee will only be paid in the event of default, with all other debtors paying the same interest rate. Interbank lending is subject to a participation constraint that accounts for the distribution of idiosyncratic shocks drawn by lending banks and the aggregate state of the economy.

For the domestic market, the savings banks require the expected real return from granting each interbank loan to be equal to their expected real funding rate, using the household Euler equation. This can be written as

$$\begin{aligned} 1 = \mathbb{E}_t \left[\tfrac{\Lambda_{t,t+1}}{\Pi_{t+1}^C} \left[1 - F(\bar{\omega}_{t+1}(b), \sigma_{\omega,t+1}) \right] R_t^{IB,H}(b) \right] \\ + \mathbb{E}_t \left[\tfrac{\Lambda_{t,t+1}}{\Pi_{t+1}^C} (1-\mu) \int_0^{\bar{\omega}_{t+1}(b)} \omega R_{t+1}^{CR} \tfrac{CR_t(b)}{IB_t^H(b) + IB_t^F(b)} dF(\omega, \sigma_{\omega,t+1}) \right] \end{aligned} \tag{2.27}$$

where $F(\bar{\omega}(b), \sigma) \equiv \int_0^{\bar{\omega}(b)} f\left(\omega; \frac{-\sigma^2}{2}, \sigma^2\right) d\omega$ is the cumulative density function up to $\bar{\omega}(b)$, with probability density function $f\left(\omega; \frac{-\sigma^2}{2}, \sigma^2\right)$. Note that this implies that the value $F(\bar{\omega}_{t+1}(b), \sigma_{\omega,t+1})$ is the probability of default. Because all banks will choose the same leverage ratio, individual bank net worth does not effect the interest rate paid on

credit and equation (2.27) will therefore also hold if the index b is dropped, with the variables treated as the aggregate averages.[8]

When taking positions in the cross-border interbank market, we assume that savings banks incur additional monitoring costs $\Gamma_{IB,t}$ that are increasing in the exposure of the destination country to cross-border debt, and to risk within the economy. Such costs reflect factors such as asymmetric information, counterparty risk as well as differences in cross-border macroeconomic conditions. Specifically, it is given by

$$\Gamma_{IB,t} = \zeta_{IB}\left[\left(1-\exp\left(\frac{IB_t^F - CB_t^* - IB_t^{F^*}}{P_t^C Y_t}\right)\right) + \zeta_\sigma\left(\frac{\sigma_{\omega,t}^*}{\sigma_\omega}-1\right)\right] \tag{2.28}$$

where the second element in the fraction highlights the additional increase to the monitoring costs following a shock to the variance of the idiosyncratic loan return shock. That is, country-specific risk shocks will cause an increase in the finance premium of borrowing banks in the cross-border interbank market. Therefore, the participation constraint for international interbank loans can be expressed as

$$\begin{aligned} 1 = \mathbb{E}_t\left[\frac{\Lambda_{t,t+1}}{\Pi_{t+1}^C}\left(1-\Gamma_{IB,t}\right)\left[1-F(\bar{\omega}_{t+1}\left(b^*\right),\sigma_{\omega,t+1}^*)\right]R_t^{IB,F}\left(b^*\right)\right] \\ + \mathbb{E}_t\left[\frac{\Lambda_{t,t+1}}{\Pi_{t+1}^C}(1-\mu)\frac{G(\bar{\omega}_{t+1}(b^*),\sigma_{\omega,t+1}^*)}{\bar{\omega}_{t+1}(b^*)}R_t^{IB}\left(b^*\right)\frac{IB_t(b^*)}{IB_t^H(b^*)+IB_t^F(b^*)}\right] \end{aligned} \tag{2.29}$$

where $G(\bar{\omega}_{t+1}\left(b^*\right),\sigma_{\omega,t+1}^*) \equiv \int_0^{\bar{\omega}_t(b)}\omega dF(\omega,\sigma_t)$ and $F_t^b = F(\bar{\omega}_t\left(b\right),\sigma_t)$. Equation (2.29) implies a spread in the cross-border interbank market $\frac{R_t^{IB,F}(b^*)}{R_t^S}$ that is a function of the monitoring cost $\Gamma_{IB,t}$, which itself is an increasing function of total cross-border exposure. In other words, the higher the volume of cross-border loans, the higher the spread required to compensate savings banks for the increase in credit risk. In a similar vein, aggregate shocks that lead to a decline in nominal domestic GDP will cause the ratio of net foreign assets to output to increase, thereby leading to a rise in the spread. Also, the spread is increasing in the standard deviation of the loan return shock: a higher $\sigma_{\omega,t}$ will increase the risks of default by making lower realization of $\omega_t(b)$ more likely.

2.3.3 Interbank Credit Market

To model the over-the-counter structure of the interbank market, we follow Bernanke et al. (1999) in our treatment of the lending contract. The lending banks choose credit

[8] As banks are atomistic, $\Lambda_{t,t+1}$ is independent of the idiosynctratic shock $\omega_{t+1}\left(b\right)$ drawn by the bank, thus implying irrelevance of $N_t\left(b\right)$ and allowing aggregation.

to the non-financial private sector CR_t, the volume of interbank lending IB_t^H and IB_t^F, and interest rates $R_t^{IB,H}$ and $R_t^{IB,F}$ to maximize their expected real net worth. The banks pay a fraction $(1-\gamma)$ of their profits as a dividend, with the remaining surplus retained as internal equity finance. Substituting in the expression for $\bar{\omega}_{t+1}$ the problem is written as

$$\max_{X_t} \mathbb{E}_t \left[\frac{\Lambda_{t,t+1}}{P_{t+1}^C} \gamma \left[1 - G\left(\bar{\omega}_{t+1}\right) - \left(1 - F\left(\bar{\omega}_{t+1}\right)\right) \bar{\omega}_{t+1} \right] R_{t+1}^{CR} CR_t \right] \tag{2.30}$$

where $X_t = \left\{ CR_t, IB_t^H, IB_t^F, R_t^{IB,H}, R_t^{IB,F} \right\}$ is a vector of controls, dropping the individual bank index. The maximization is subject to the bank balance sheet equation (2.19), the interbank demand equations (2.20) and (2.21), the composite interest rate (2.22), the loan-to-value equation (2.24), and the saver bank participation constraints given in equations (2.27) and (2.29).

The solution to the contract problem yields a condition that determines the wedge between the nominal risk-free rate R_t^S, and the expected return from credit to the non-financial sector R_{t+1}^{CR}. We can express this as

$$\mathbb{E}_t \left[\frac{R_{t+1}^{CR}}{R_t^S} \right] = \mathbb{E}_t \left[s \left(R_t^S, R_t^{IB,H}, R_t^{IB,F}, \Gamma_{IB,t}^*, \frac{IB_t}{CR_t}, \bar{\omega}_{t+1}, \sigma_{\omega,t+1} \right) \right] \tag{2.31}$$

with key arguments given, although the nominal stochastic discount factors of both countries are also arguments of function s. In this solution, which is given in full in the online appendix, the expected real return to lending is equated with the real marginal cost of external finance. Because the solution is a function of the leverage rather than the bank size, the contract interest rates will be independent of the bank's own history of shocks. As leverage increases, the capital-asset ratio $\frac{N_t}{CR_t}$ falls, the probability of default increases, and the marginal cost of borrowing rises. This is the financial accelerator mechanism; if, for instance, an adverse shock reduces the net worth of the banking sector, bank leverage will increase, and so will the credit wedge s, causing a further deepening of the downturn.

2.3.4 Firm and Household Credit

As discussed previously, firm loans are treated as equivalent to equity, and so the return on firm credit is simply the gross return on capital, R_t^K, defined in equation (2.25). The

repayment rate on household credit is the contracted nominal rate R^M_{t-1}. The optimality condition implies the zero-arbitrage condition

$$\mathbb{E}_t\left[\frac{\Lambda_{t,t+1}}{P^C_{t+1}}R^{CR}_{t+1}\right]=\mathbb{E}_t\left[\frac{\Lambda_{t,t+1}}{P^C_{t+1}}R^M_t\right]=\mathbb{E}_t\left[\frac{\Lambda_{t,t+1}}{P^C_{t+1}}R^K_{t+1}\right],$$

which must hold in equilibrium.

2.4 Monetary Policy

The monetary authority sets the nominal short-term interest rate in response to deviations of the consumer price inflation rate from the union-wide inflation target $\bar{\Pi}^{EMU}$ and off-trend output growth

$$R_t=\left[\bar{R}\left(\frac{\Pi^{EMU}_t}{\bar{\Pi}^{EMU}}\right)^{\varphi^\pi}\left(\frac{Y^{EMU}_t}{Y^{EMU}_{t-1}}\right)^{\varphi^y}\right]^{1-\varphi^r}R^{\varphi^r}_{t-1}\exp(\varepsilon^m_t) \tag{2.32}$$

with weights φ^π and φ^y attached to inflation and output growth respectively. There is inertia in the rule governed by φ^r. The union-wide variables Π^{EMU}_t and Y^{EMU}_t are weighted averages of the home and foreign country variables:

$$\Pi^{EMU}_t=\frac{P^{EMU}_t}{P^{EMU}_{t-1}}=\frac{\left(P^C_t\right)^n\left(P^{C^*}_t\right)^{1-n}}{\left(P^C_{t-1}\right)^n\left(P^{C^*}_{t-1}\right)^{1-n}} \tag{2.33}$$
$$Y^{EMU}_t=\left(Y_t\right)^n\left(Y^*_t\right)^{1-n}$$

With a single policy rate, the economy as presented to this point features a unit root stemming from a single savings rate across both economies. As savers in both countries face the same return on assets, long-run effects from transitory shocks would prevail. For instance, if one of the economies were to draw a positive supply shock, its net foreign asset position would improve and the economy will have a current account surplus that would persist in the long run, with a permanent increase in the wealth of savers. To restore the stationary property of the model, we assume, consistent with past modelling practise in open-economy models, that the central bank applies a small premium on the refinancing rate that depends on the net foreign asset position NFA_t of the home

country.[9] The rates paid on central bank credit CB_t are determined by

$$R_t = R_t^P - \vartheta_t \left(\exp \left[\kappa \frac{NFA_t}{P_t^Y Y_t} \right] - 1 \right).$$

where ϑ_t is a stationary, mean one shock to the premium, and κ the premium elasticity. $R_t^P = R_t^{P*}$ is the central policy rate, and R_t and R_t^* the rates paid on central bank credit.

Central bank funds are in zero net supply so if savings banks in the home country borrow from the central bank, it follows that foreign country savings banks are depositors, and $R_t > R_t{}^*$. The risk premium will cause the net foreign asset position of banks in each country to adjust until $NFA_t = NFA_t^* = 0$ and $R_t = R_t^*$. The structure of the premium implies that there will be small positive profits in equilibrium which are transferred equally to savers in the union. In the numerical simulations we choose κ sufficiently low to allow the rates to be very close, generating persistent effects of shocks whilst ensuring that the model is stationary.

2.5 Market clearing conditions

In each economy, the labour market is in equilibrium when total supply by households equals the demand from intermediate good producers

$$L_t^D = \lambda L_t + (1 - \lambda) L_t^B. \tag{2.34}$$

The corresponding domestic capital market equilibrium condition is given by

$$K_t^D = K_{t-1}. \tag{2.35}$$

Total demand for domestically produced goods include the demand from domestic households $H_t^T = \lambda H_t + (1 - \lambda) H_t^B$, demand from foreign consumers $X_t^T = \lambda X_t + (1 - \lambda) X_t^B$, demand from capital producers $I_t^K \left(1 - \zeta^K \left(I_t^K / I_{t-1}^K - 1 \right)^2 \right)$ and from housing good producers $I_t^D \left(1 - \zeta^D \left(I_t^D / I_{t-1}^D - 1 \right)^2 \right)$ which are net the adjustment costs, and demand by the government, which is given as a proportion g_t of output Y_t. The implied real resource constraint is then

$$Y_t = H_t^T + X_t^T + I_t^K + I_t^D + g_t Y_t \tag{2.36}$$

[9] See Schmitt-Grohe and Uribe (2003) for a full discussion of the techniques used to remove the random walk in open-economy models.

with g_t following a stationary stochastic process. The net foreign asset position evolves according to the following nominal law of motion

$$IB_t^{F^*} - IB_t^F - CB_t = R_{t-1}^{IB,F^*} IB_t^{F^*} - R_{t-1} CB_{t-1} - R_{t-1}^{IB,F} IB_t^F + TB_t, \tag{2.37}$$

where the trade balance is defined as

$$TB_t = P_t^P X_t - P_t^{IM} IM_t. \tag{2.38}$$

The bilateral terms of trade are given by:

$$ToT_t = \frac{P_t^{IM}}{P_t^X} \tag{2.39}$$

and, as discussed previously, the central bank funds are in zero net supply worldwide, so

$$nCB_t + (1-n)CB_t^* = 0. \tag{2.40}$$

3 Calibration and Parametrization

A number of the structural parameters of our model are calibrated with the aim of matching key empirical first moments. Other parameters are based on previous estimates in the literature, see table 1.

On the household side, we fix the fraction of savers λ in each economy to 0.65, close to the estimate obtained by Quint and Rabanal (2014). The discount factor of savers (borrowers) β (β_B) is chosen to be 0.995 (0.89), ensuring a nominal steady-state return on risk-free savings of around 4%. External habit in consumption κ is set at 0.564 according to estimates of Christoffel et al. (2008) for the euro area. The relative share of non-durables in consumption ϱ is calibrated to be 0.82 to target the output share of housing investment. The inverse of the Frisch labour supply elasticity ϕ is parametrized to be 0.4 (cf. Quint and Rabanal 2014). The quasi-share of domestic goods in total consumption τ^C is fixed at 0.75 to ensure a steady-state share of imports in consumption of 25%. The elasticity of substitution between domestic goods and imports θ^C is set at 1.9 in line with Quint and Rabanal (2014) estimates.

On the production side, we choose a value of 0.3 for the share of labour α in the Cobb-Douglas production function. Capital depreciation δ_K and housing depreciation δ_D

are assumed to be 10% per annum. Adjustment costs ζ^K in capital investment are fixed at 5.2 (following estimations in Christoffel et al. 2008), while those in housing investment (ζ^D) are set at 1.7 as estimated in Quint and Rabanal (2014). The elasticity of substitution across the final goods σ is chosen so as to ensure a steady state mark-up of 1.35 and the Calvo parameter ξ is set to be 0.9, both in line with estimates obtained by Christoffel et al. (2008).

On the banking side, savings banks' monitoring costs, μ, are assumed to be 0.2 as in Quint and Rabanal (2014) and Carlstrom and Fuerst (1997). For the borrowers' loan-to-value ratio, we use the estimated value of $m = 0.55$ from Iacoviello (2005). The steady state standard deviation of the loan return shock, σ_ω, and the bank dividend payment rate, $1 - \gamma$, are calibrated to 3.39 percentage points and 4.53% respectively to target a steady-state value of the loan-to-value ratio of banks $\bar{\omega}$ of 0.9, in line with typical industry leverage ratios. The default rate of banks is calibrated to be around 0.4% in steady state, matching the average historical default rate in the banking industry over the period 1970-2010, as well as an equilibrium spread for mortgage and interbank loans of around 1.75 percentage points and 10 basis points respectively over the policy rate, in line with typical measures of the average spreads (see e.g. ECB 2009*b*). The share of cross-border intra-euro area interbank borrowing τ^{IB} is set at 0.75 to match figures reported by Colangelo and Lenza (2013). The elasticity of substitution between domestic and foreign interbank funding θ^{IB} is fixed at 2, implying that these sources of funding are not perfect substitutes.

On the policy side, we fix the share of government spending in GDP at 20%. Together with the other parametrization of our model, this ensures that we are able to get close matches of the relative spending shares of consumption (59%), investment (21%) and housing investment (4.5%) in GDP with their empirical first moments for the euro area as a whole. Regarding monetary policy, we follow Christoffel et al. (2008) and set the central bank response to inflation φ^π to 1.9 and to output growth φ^y to 0.15. Policy inertia is set at 0.87.

Finally, the standard deviations and persistence coefficients of the shock processes are largely taken from Christoffel et al. (2008), with the exception of the risk shock, which is taken from Quint and Rabanal (2014), and the government spending shock, which has been calibrated on the basis of estimates obtained by Smets and Wouters (2003). For

Parameter	Description	Value
β	Patient agent discount factor	0.995
ϱ	Utility weight of non-durable consumption	0.82
τ^C	Home-bias in consumption	0.75
σ	Elasticity of substitution across consumption varieties	3.86
σ_ω	Standard deviation of loan return shock	0.0339
γ	Retained share of bank profits	0.947
τ^{IB}	Home-bias in interbank borrowing	0.75
g	Steady-state G/Y	0.2
λ	Fraction of savers	0.65
β^B	Borrowers discount factor	0.89
ϵ_C	Habits formation	0.564
ϕ	Inverse Frisch elasticity	0.4
θ_C	Elasticity between domestic goods/imports	1.9
α	Capital share of production	0.3
β	Household discount factor	0.99
δ^K	Capital depreciation rate	0.025
δ^D	Housing depreciation rate	0.025
ζ^K	Capital adjustment parameter	5.2
ζ^D	Housing adjustment parameter	1.75
ξ	Calvo parameter	0.9
μ	Monitoring costs	0.2
m	Borrowers LTV ratio	0.55
θ_{IB}	Elasticity of substitution between domestic/cross-border interbank credit	2
ζ_{IB}	Cross-border interbank cost coefficient	0.5
φ^y	Taylor rule response to output growth	0.15
φ^π	Taylor rule response to inflation	1.9
φ^r	Taylor rule persistence	0.87
$\bar{\Pi}$	Inflation target	1.005

Table 1: Calibration and parametrisation of model parameters.

the interbank risk premium shock, for which no estimates in the literature are available, we assume a persistence of 0.8 and a standard deviation of 0.2. These are shown in table 2.

Parameter	Description	Value
σ_A	Technology shock	0.0126
σ_G	Government spending shock	0.00325
σ_{IB}	Interbank cost shock	0.2
σ_σ	Risk shock	0.00339
σ_M	Monetary policy shock	0.00115
ρ_A	Technology shock	0.9
ρ_G	Government spending shock	0.95
ρ_{IB}	Interbank cost shock	0.8
ρ_σ	Risk shock	0.85

Table 2: Parametrisation of shock parameters.

4 Numerical Results and Analysis

To evaluate the model dynamics, we compute a second order Taylor approximation of the decision and transition functions and simulate impulse response functions. In a first step, we look at the implication of our interbank market setup for the transmission of monetary policy by considering a standard monetary policy shock. In a second step, we analyze how frictions in the cross-border interbank market may affect the dynamics of the economy in the face of country-specific idiosyncratic shocks.

4.1 The interbank market and the transmission of monetary policy

Figure 1 shows the impulse responses of a number of variables to a reduction in the union-wide policy rate and compares these to a modified version of our model in which the interbank frictions are shut off, that is, the model collapses to one of complete financial markets where the spread between bank lending rates and the policy rate is fixed to its steady state value.

In both instances, the interest rate controlled by the monetary authority drops by about the same amount initially. In our baseline model, however, the unanticipated reduction in interest rates leads to an increase in the value of collateral held by lending banks.

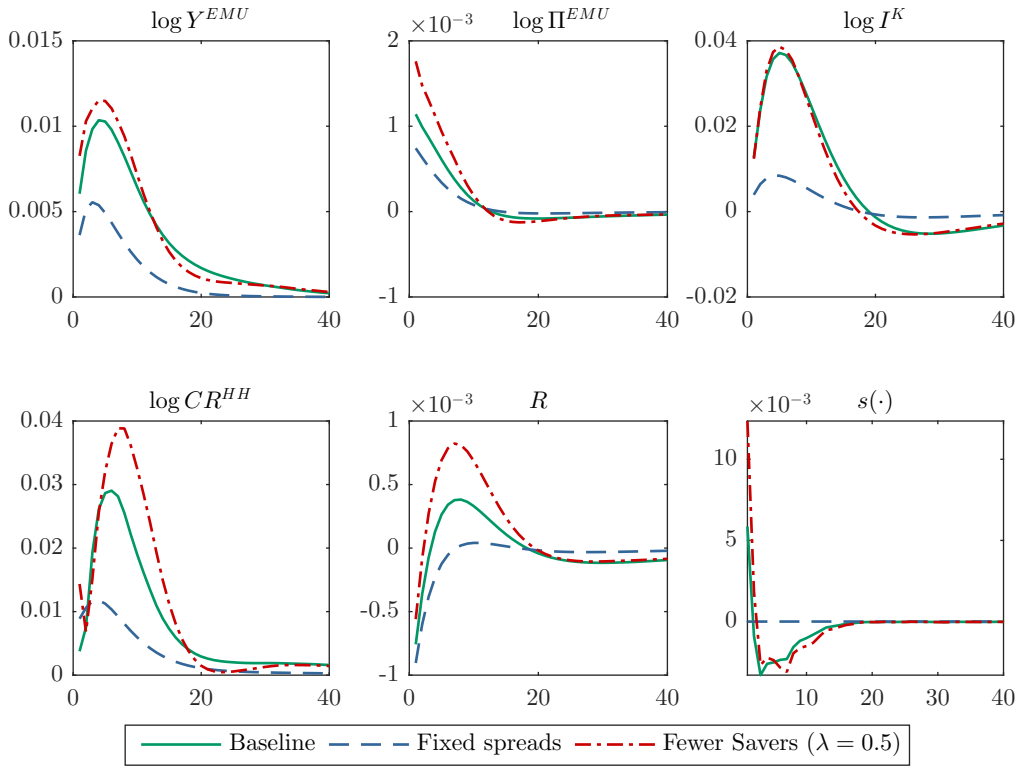

Figure 1: Impulse response functions to a negative monetary policy shock. $s(\cdot)$ is the external finance premium. Deviations in levels from the deterministic steady state.

This, in turn, lowers their funding costs in the interbank market as the perceived risk of default falls. Lending banks operating under perfect competition will pass-through the relief in funding costs to their final customers, causing mortgage rates and financing costs faced by non-financial firms to drop by more than the initial reduction in the key policy rate.

It is this additional fall in the borrowing conditions of households and firms that then leads to more investment, more housing demand and, ultimately, higher domestic demand and inflation in the currency union. In other words, like in Bernanke et al. (1999), the transmission of a conventional change in monetary policy is more powerful in affecting broader macroeconomic conditions. However, unlike in Bernanke et al. (1999), the amplification in transmission comes directly from banks operating in an interbank market characterized by uncertainty on part of savings banks when extending short-term credit to counterparties in need of liquidity.

This implies that there are major differences to a situation where the financial accelerator operates directly at the balance sheet of firms. The impact on aggregate demand, as well as the strength of the pass-through of interbank conditions to final borrowing conditions, will ultimately depend on three factors: the relative share of saver and borrower households in the economy, the structure of lending banks' balance sheets and the degree of competition in the lending market. Starting with the latter, the less concentrated the lending market is, the stronger is the pass-through and the more pronounced are the effects on the real economy. That is, modifications of our model along the lines of Gerali et al. (2010), introducing monopolistic competition in the banking sector, can be expected to dampen the accelerator effect as banks would pass-on lower interbank funding costs at a pace slower than under our baseline model. Similarly, the larger the share of bank lending to households, the larger the impact on output, given the role played by private consumption in aggregate demand. And, finally, although the friction lowers borrowing costs for firms and impatient households, figure 1 also shows that the policymaker keeps the interest rate higher relative to the fixed spread economy due to increased output and inflation. Saver households hence face a higher savings rate, causing them to consume less non-durable and durable goods in response. This effect offsets, to some extent, the increase in housing investment coming from borrowers.

We illustrate this last point in 1: the red dashed line shows our baseline model, assuming, however, a smaller share of savers λ=0.5. As expected, because the financial friction reduces borrowing costs beyond the initial change in the policy rate, the more borrowers there are, the larger the accelerator effect. Fewer savers, in turn, imply that the offset from a higher policy, and hence savings rate, will also be smaller.

Overall, therefore, our simulations tend to suggest that, contrary to previous findings in the literature (e.g. Hilberg and Hollmayr 2011), the presence of an interbank market can, and in many circumstances is very likely to, amplify changes in the key policy rate. And although the mechanism is similar to the well-known financial accelerator, there are noticeable differences in the way our model setup can give rise to changes in the transmission of monetary policy.

4.2 Asymmetric shocks and cross-country spillovers

A key result of the previous section is that union-wide shocks will propagate differently through the economy once financial frictions are allowed for and that it matters whether these frictions are operating on the banking or the firm side. In this section we will focus on the implications of our interbank market setup for the propagation and impact of idiosyncratic country-specific shocks. Specifically, we look at how a positive shock to the variance of the idiosyncratic loan return shock $\omega(b)$ will affect the behavior of banks in the cross-border interbank market and analyze the footprint this will ultimately leave on aggregate demand.

Recall that savings banks incur additional monitoring costs when taking positions in the cross-border interbank market. These costs are a function of an economy's net foreign exposure and the prevailing level of "economic" risk (cf. equation 2.28). Therefore, a shock that raises the skewness of the distribution of $\omega(b)$ in one country but not in the other, and hence increases the relative risk of bank default, will cause savings banks to raise the risk premium they charge to borrowers resident in the economy hit by the shock, even though the average loan return remains unchanged.

This can be seen in figure 2: in our baseline model the funding rate in the cross-border interbank market, $R_t^{IB,F}$, increases by significantly more than compared to a model in which banks are insensitive to both macroeconomic and counterparty risks. As a result, banks with a liquidity deficit will partly substitute more expensive foreign borrowing with domestic borrowing, forcing consumers to dial back more vigorously their imports in response. Naturally, this effect will be stronger the more heavily the economy's banking sector relies on cross-border interbank market funding, $\left(1-\tau^{IB}\right)$, or, similarly, the more difficult it is to switch foreign with domestic funding (θ_{IB}). This also means that, should countries differ in their financial structure, symmetric shocks too can cause differences in banks' funding costs across the currency union. For example, an economy which predominantly finances loans to firms and households using funds from abroad, will see its overall funding costs increase more sharply in the face of an adverse shock, thereby causing a steeper economic contraction than compared to an economy that mainly relies on domestic funding. This stylized finding has been one of the key aspects of the crisis in peripheral euro area economies: because many banks funded large parts of their liquidity needs abroad, the sudden market freeze meant that aggregate imports

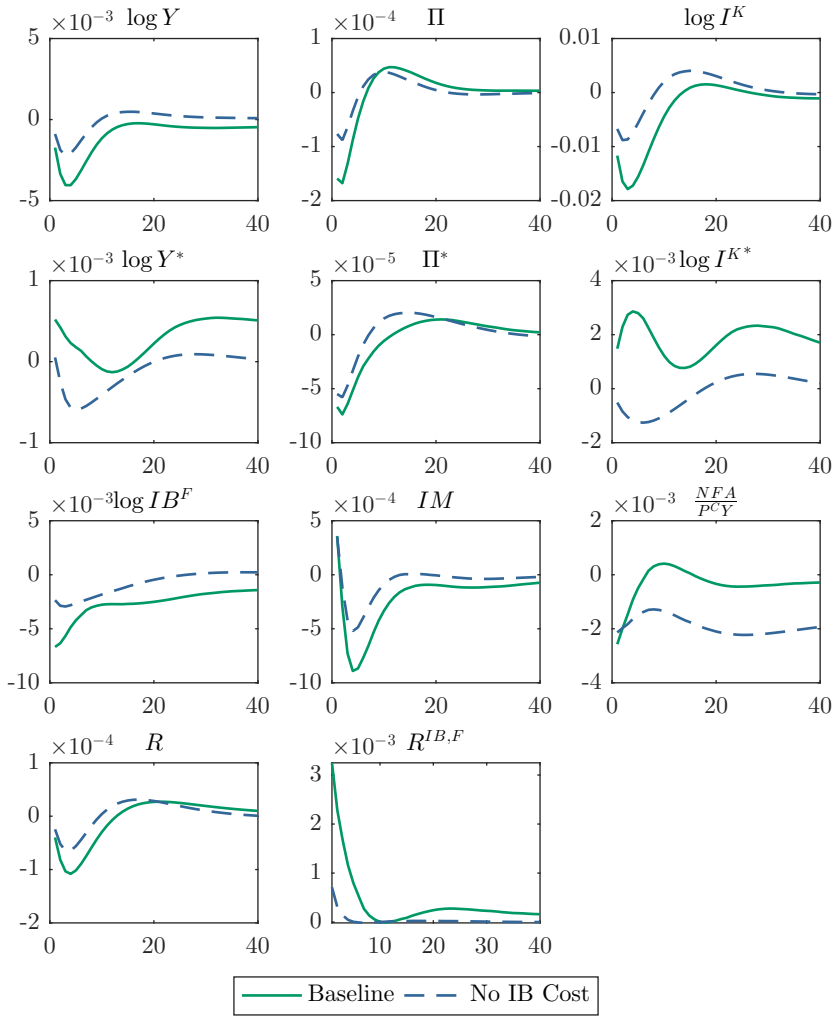

Figure 2: Impulse response functions to a transitory risk shock in the home country, comparing baseline model with a version with $\zeta_{IB} = 0$. Deviations in levels from the deterministic steady state.

fell drastically, thereby reinforcing the macroeconomic fallout caused by the collapse in domestic demand and the rise in funding costs.

Cross-border monitoring costs are, however, only an amplifier of a natural response of our modelling choice. As can be seen in figure 2, banks resident in the foreign economy would have increased their cross-border interbank rates even in the absence of these costs and despite a measurable reduction in the union-wide monetary policy rate. The reason has to do with the built-in increase in the risk of bank default: with output contracting

in response to the shock, domestic banks' leverage rises, causing foreign banks to increase their lending rates.

What is more, with lending to the real economy having become riskier in the wake of the shock, domestic savings banks too will ration their supply of interbank funds, and will increase the rate they charge on the remaining funds, causing a contraction in credit supply to the real economy. The consequences are well-known: with credit less abundant and more expensive, both households and firms reduce their investment and housing activities, amplifying the contraction in aggregate demand that would have prevailed in the absence of frictions in the interbank market.

The consequence is that interbank markets characterized by risky lending and costly state verification have the potential to render monetary policy less effective by contributing to the fragmentation of trades across borders, something that has become evident in the euro area during and after the sovereign debt crisis. At that time, the transmission of the ECB's monetary policy to banks in the periphery had become severely impaired: although it cut its main refinancing rate by 85 basis points between July 2012 and June 2014, bank lending rates to firms in Spain, for example, only fell by some 20 basis points over the same period, reflecting, in part, effective credit rationing in the (cross-border) interbank market. In response to these impairments, the ECB, starting in June 2014, decided on a number of non-standard measures that aimed at restoring the transmission of monetary policy. Some of these measures are subject of our analysis in the next section.

5 The effects of unconventional monetary policy

In this final section we ask as to whether or not recent non-standard monetary policy measures have been able to overcome, or mitigate, frictions in the interbank market. The two policies we discuss are long-term central bank refinancing operations and asset purchases.

5.1 Long-term refinancing operations

In our model economy, savings banks have access to funding from the central bank (cf. Section 2.3.2). In addition to standard one-period loans to banks, in this policy exercise, the operations of the central bank may take the form of multi-period loan contracts, similar to the ECB's LTROs.[10] To prevent corner solutions whereby savings banks will choose only short-term, or only long-term funding, the central bank sets a single target policy rate on multi-period bonds, and allows the short-term rate to be set via the zero-arbitrage condition. As discussed in section 2.3.2, the short-term central bank funds will be in zero net supply union-wide. This is also the case with long-term funds. Indeed, in equilibrium, we will find that savings banks will not hold long-term bonds at all; the availability of these loans is sufficient to introduce a wedge between the policy rate on long-term refinance operations and the household saving rate.

To maintain tractability and keep the number of state variables manageable, we follow Rudebusch and Swanson (2012)[11] and introduce multi-period loan contracts using geometrically decaying repayments over an infinite horizon. This setup reflects the aggregation of a large number of loans at different points of repayment and of different maturities. As well as introducing just one new state variable rather than potentially very many with long maturities, the appeal is that using infinitely long loans with geometrically declining repayments allows us to control the average maturity $\psi \in [0, 1)$ with just one parameter, nesting the possibility of $\psi = 0$, in which case it collapses to a standard one-period loan contract.

Every period t, a savings bank can take out a new loan CB_t and agree to repay an infinite number of declining payments such that the total amount due at period t is given by:

$$CB^T_{t-1} = \sum_{k=1}^{\infty} \psi^{k-1} R^{LT}_{t-k} CB_{t-k} \tag{5.1}$$

When $\psi > 0$, R^{LT}_t is no longer equivalent to an interest rate. To analyze the role of the LTRO policy, we assume that the central bank chooses R^{LT}_t so that the average interest

[10] See e.g. https://www.ecb.europa.eu/press/pr/date/2011/html/pr111208_1.en.html for information on this policy.

[11] Described in detail to analyse term premia on bonds in a working paper version of the article (see Rudebusch and Swanson 2008). Used to introduce multi-period loan contracts in Benes and Lees (2010).

rate on long-term borrowing equals the policy rate R_t. As we are using perpetual loan repayments, we measure the average duration using Macaulay's duration of a stream of payments. It is then straightforward to calculate the equivalent average nominal interest rate on the amount borrowed from the total amount repaid. We find this leads to the following relationship between the rate R_t^{LT} and the policy rate R_t:

$$R_t = \left(\frac{R_t^{LT}}{1-\psi} \right)^{(1/d)} \tag{5.2}$$

with average loan duration $d = R/(R-\psi)$, where R is the steady-state policy rate.[12] We can then express equation (5.1) in recursive form as

$$CB_t^T = \psi CB_{t-1}^T + R_t^{LT} CB_t. \tag{5.3}$$

The important thing to note is that even if the bank does not borrow from the central bank in equilibrium, as will be the case with purely symmetric shocks, the availability of these loans is sufficient to have an important impact on the household saving rate, a point we will return to later. Using equation 5.3 as a constraint in the profit maximization problem of the savings bank leads to the following first-order conditions

$$\phi_t = \mathbb{E}_t \left[\frac{\Lambda_{t,t+1}}{\Pi_t^C} \left(1 + \phi_{t+1}\psi\right) \right] \tag{5.4}$$

$$\phi_t R_t^{LT} = \mathbb{E}_t \left[\frac{\Lambda_{t,t+1}}{\Pi_t^C} R_t^S \right] \tag{5.5}$$

This, with equation (5.2), gives the spread between the policy rate R_t and the deposit rate R_t^S. ϕ_t is the real present value of the Lagrange multiplier on the law of motion of repayments due, and is a nominal pricing kernel for central bank credit. When $d = 1$ and $\psi = 0$, then $R_t^{LT} = R_t = R_t^S$ as in the standard model, and ϕ_t is just the nominal stochastic discount factor. As the loan duration increases so $\psi > 1$, the implied future stream of payments increase and $\psi_t > \frac{\Lambda_{t,t+1}}{\Pi_{t,t+1}}$.[13]

Figure 3 shows the LTROs at work, comparing the impulse response functions to the

[12] For perpetual loan repayments, the average loan duration is measured using Macaulay's duration of a stream of payments, given by $d_t = \sum_{t=1}^{\infty} tPV_t / \sum_{t=1}^{\infty} PV_t$ where PV_t is the present value of the cash flow (see e.g. Marrison 2002). Applying this to our example, we find in simulations that d_t experiences only tiny fluctuations around its steady state value, and so we use the steady state value as a close approximation. This can be simplified to $d = \frac{R}{R-\psi}$. It is then straightforward to calculate the average interest rate given that borrowing is a convergent series.

[13] One difficulty with our approach is that introducing the policy, or changing the average duration,

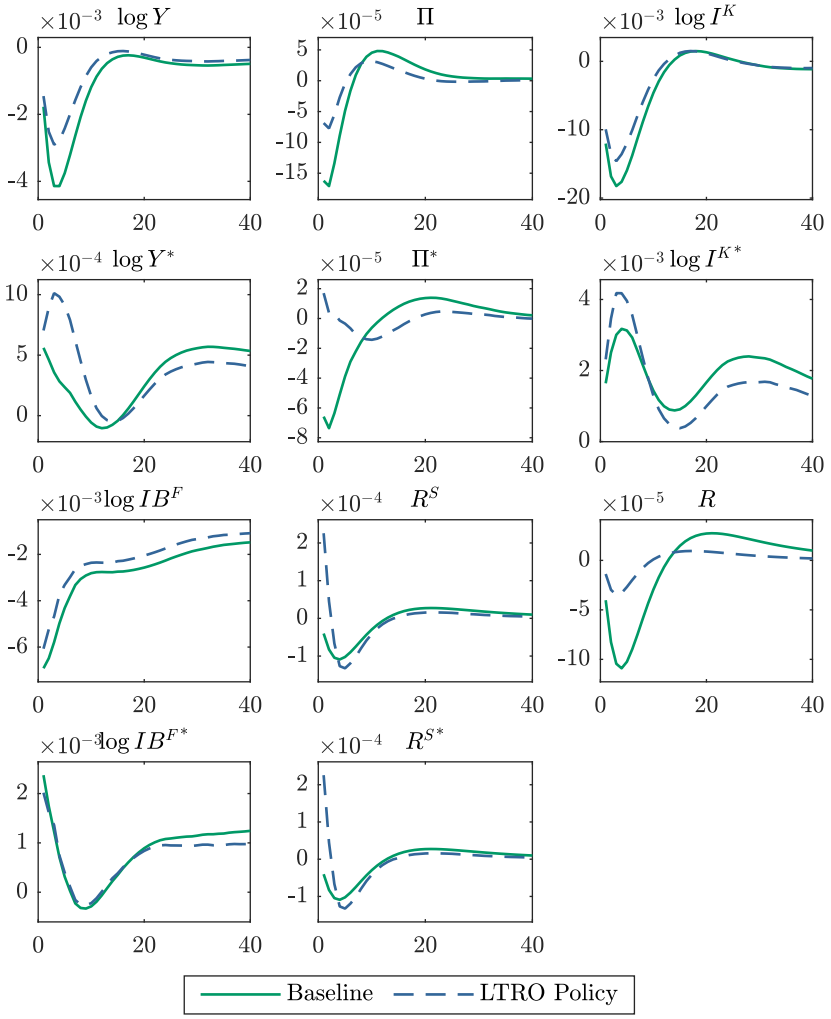

Figure 3: Impulse response functions to a transitory risk shock with central bank with and without LTRO policy response. Deviations in levels from deterministic steady state.

same risk shock analyzed before, once with $d = 1$ and once with $d = 16$.[14] This calibration mimics the four-year loan duration of the ECB's targeted LTROs introduced in

during a model simulation would cause the mapping between the repayment rate and the policy rate to be lost. For example, the average loan duration stems from the continued existence of loans with a fixed parameter ψ. If ψ were time varying, it would be considerably more difficult to compute the average loan duration, or the average rate across the loans. For this reason, we draw comparison between a model in which the central bank provides standard one-period credit, and a long-term refinancing case with $\psi > 0$ and duration $d > 1$ fixed.

[14] This corresponds to an average loan duration ψ of 0.9422.

2014. The policy has two major effects. First, in the face of an adverse shock, fewer cuts in policy rates are required to achieve the equivalent stimulus in a multi-period loan economy. The reason is that the reduction in policy rates lowers the average rates for longer and, hence, reduces by more the effective present funding costs of forward-looking banks. That is, long-term refinancing operations with fixed interest rates, such as the latest series of targeted LTROs, ensure planning certainty for banks and thereby, in practice, provide major help with respect to maturity transformation between longer-term lending and often short-term refinancing. And with banks passing on immediately the additional funding cost relief to the ultimate borrowing conditions of households and firms, policymakers are able to frontload required accommodation and thereby to mitigate the economic downturn.

The second interesting feature of LTROs is their asymmetric distributional effects when economies are hit by idiosyncratic shocks. As we argued before, once $d > 1$ ($\phi_t > 0$), the deposit rate in each country will no longer be fixed to the policy rate by the zero arbitrage condition. As equations (5.2) and (5.5) highlight, the spread between the policy rate and the deposit rate depends on the Lagrange multiplier, itself a function of the household stochastic discount factor. Specifically, using equations (5.2) and (5.5) we can give the spread as

$$\frac{R_t}{R_t^S} = \frac{\mathbb{E}_t\left[\frac{\Lambda_{t,t+1}}{\Pi_t^C}\right]}{\left[\phi_t\left(1-\psi\right)\right]^{1/d}}$$

where

$$\phi_t = \mathbb{E}_t\left[\frac{\Lambda_{t,t+1}}{\Pi_t^C}\left(1+\phi_{t+1}\psi\right)\right].$$

So, asymmetric shocks will affect the spread differently in each country as a first-order effect. From equations (5.4) and (5.5), a first order approximation suggests that:

$$\frac{R_t^S}{\mathbb{E}_t\left[1+\phi_t\psi\right]} = \frac{R_t^{S*}}{\mathbb{E}_t\left[1+\phi_t^*\psi\right]}$$

In other words, if the expected path of the nominal stochastic discount factor is greater in the domestic economy than in the foreign, then it follows that $\mathbb{E}_t\phi_{t+1} > \mathbb{E}_t\phi_{t+1}^*$, which implies that $R_t^S > R_t^{S*}$.

This can be seen in figure 3. Because consumers in the foreign economy, following the shock, expect a lower future marginal utility of consumption relative to the domestic country, LTROs, by easing financial conditions abroad by more, are able to fully offset

any negative spillovers of the original shock to the rest of the currency union. Of course, the extent of the easing can differ from shock to shock, but LTROs can generally be thought of as a powerful stabilization tool in a currency union. This has been confirmed by recent ECB analysis (ECB 2017). They show that from June 2014 to July 2015, i.e. after the first TLTRO operation, non-bidders in vulnerable and non-vulnerable economies reduced their lending rates by about the same amount, while after the second operation, in the period from March to December 2016, the reduction in lending rates was larger in non-vulnerable economies, consistent with the predictions from our model. This emphasizes that the sheer existence of the policy is enough to reduce financing conditions across the currency union and, hence, to help central banks reach their price stability objectives.[15]

5.2 Asset Purchases

The second policy instrument we analyze are asset purchases by central banks, which have become an integral part of policymakers' toolkit after, and in some jurisdictions even before, the outbreak of the global financial crisis. Several attempts have been made in the literature to quantify the effects of such purchases.[16] On the theoretical front, Chen et al. (2012) and Gertler and Karadi (2013) have recently made useful progress in capturing the effects of asset purchases on the broader macroeconomy. In this paper, we want to focus on one element of the ECB's asset purchase programme that has received less attention in the literature and that is particularly suited to study within the context of our model setup: its ABSPP.

The aim of this programme, launched in November 2014, is to facilitate credit provision to the real economy by freeing up bank balance sheet capacity. Although the effects of securitization are more complex in practice, mainly related to regulation, the general idea behind this programme can be illustrated by assuming that the central bank purchases assets directly from banks. Indeed, one of the main reasons for banks to engage in securitization is balance sheet relief: securitization typically involves a true sale of the underlying asset to a special purpose vehicle (SPV), removing assets from the balance

[15] We tried different parameter values in the Taylor rule and found the relative impact of the availability of LTROs was unchanged.

[16] For the United States, see, for instance, Krishnamurthy and Vissing-Jorgensen (2011) and Gagnon et al. (2011); for the euro area, see, for instance, Blattner and Joyce (2016) and Altavilla et al. (2015).

sheet and thereby reducing the amount of capital that a financial institution is required to hold. We therefore follow Gertler and Karadi (2011) and treat asset purchases as if the central bank lends directly to the private sector, which is a convenient shortcut to analyzing the effects of the ECB's ABSPP.

Specifically, the central bank issues one-period bonds at the market rate and uses the proceeds to purchase a certain share Θ_t of loans from lending banks. Profits are distributed to the households via lump sum transfers.[17] The central bank budget constraint can be written as

$$\Theta_t \left(CR_t^{HH} + CR_t^F \right) = B_t^{CB} \tag{5.6}$$

$$T_t = R_t^{CR} \Theta_t \left(CR_{t-1}^{HH} + CR_{t-1}^F \right) - R_{t-1}^S B_{t-1}^{CB} \tag{5.7}$$

where T_t are transfers to households and B_t^{CB} central bank issued bonds. The first constraint is that all funds raised are used to purchase assets and the second that all profits are transferred to households.

At the start of the period during which the asset purchase will take place, the policymaker announces the purchase decision. This implies the lending banks' first-order conditions are unchanged except for the volume of loans on banks' balance sheets that changes to

$$CR_t = (1 - \Theta_t) \left(CR_t^{HH} + CR_t^F \right)$$

With this in mind, we now examine how asset purchases can help stabilize the economy in the face of an adverse shock, using again, for reasons of comparability, a risk shock in the domestic economy. Figure 4 shows the general workings of a temporary asset purchase programme. In our calibration the central bank is assumed to purchase 2% of all available assets in the first period, in equal proportions across economies, and to hold them for four years. At this point, the assets are gradually resold to the private sector, causing the central bank's balance sheet to contract by 2.5% every quarter.

The message is unambiguous: asset purchases in the form of loans, either directly or through purchases of ABS, can be an effective substitute, or complement, to reductions in the key policy rate. By reducing banks' risk exposure to the real economy, policymakers are able to lower banks' market-based funding needs and to compress their external

[17] Likewise, if there are losses, these are borne by households through lump sum taxes.

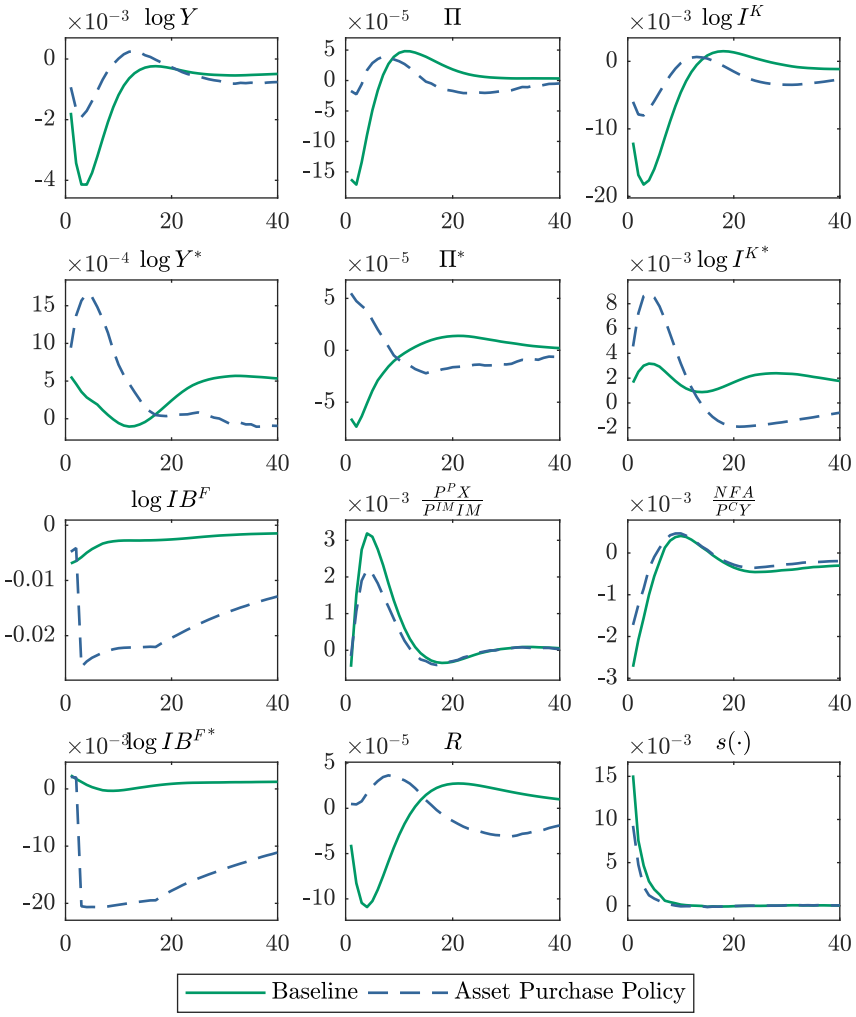

Figure 4: Impulse response functions to a transitory risk shock with central bank asset-purchase policy response. Deviations in levels from deterministic steady state.

finance premium in the interbank market. Lower interbank funding costs, in turn, are passed on to households and firms, which stimulates demand for loans and mortgages and, ultimately, investment and aggregate demand. As can be seen in figure 4, in our example purchases of loans succeed in effectively mitigating the fall in output and inflation without lowering the key policy rate. This means that, at the effective lower bound, such a policy can be an effective complement to changes in the conventional policy instrument.

Finally, in figure 5, we perform a comparative analysis of the efficiency of our two un-

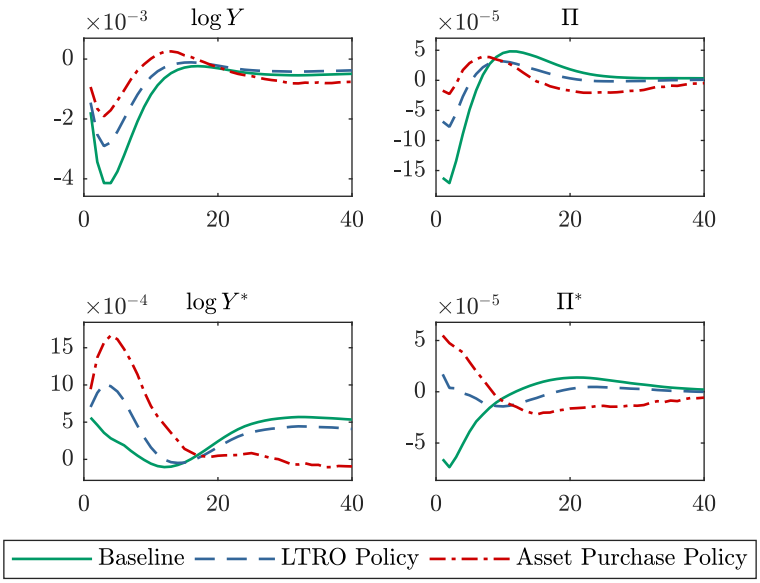

Figure 5: Impulse response functions to a transitory risk shock comparing central bank asset-purchase policy response and LTROs. Deviations in levels from deterministic steady state.

conventional policy instruments to the same transitory risk shock. To ensure broad comparability, both policies are calibrated to ensure the same target horizon of four years. The chart emphasizes that, while both policies can effectively mitigate the impact of adverse shocks on output and inflation, asset purchases, even in relatively small size, are likely to be more powerful, reflecting the direct risk transfer from private to public balance sheets. This means there is a trade-off for policymakers between policy effectiveness and risk exposure. While an analysis of the optimal policy use goes beyond the scope of this article, it may seem advisable to central banks to choose the optimal policy mix depending on the severity and persistence of the shock, also bearing in mind that very large adverse shocks may affect the supply-side of the economy through hysteresis effects. In these instances, policy may prefer to minimise the initial impact of the shock by choosing a policy that would re-establish quickly orderly trading conditions in interbank markets.

6 Conclusion

Growing levels of excess liquidity in the wake of the ECB's asset purchase programme, together with attractive conditions attached to the ECB's targeted longer-term refinancing operations, have reduced the need of banks to seek funds in the euro area interbank market. Although these measures have undoubtedly contributed to restore the transmission of monetary policy, and thereby to reinforce the economic expansion the euro area is enjoying since about mid-2013, they also mask the prevailing fragilities related to the trading of central bank reserves in a currency union characterized by structural differences across borders. Such differences may lead to persistent cross-border capital flows intermediated, in part, by banks that are likely to price interbank loans not only according to the credit quality of their counterparts, but taking also into account differences in macroeconomic risk across euro area jurisdictions.

This article showed that, at times, such frictions in the interbank market may constrain the ability of monetary policymakers to achieve their area-wide price stability objective using merely conventional policy instruments. In good times, credit frictions in the interbank market may amplify changes in the key policy rate and contribute to boost cross-border interbank loans. In bad times, pro-cyclicality in bank lending and pricing may offset efforts by the central bank to stimulate the economy.

The good news is that the crisis has proven that unconventional policy measures can be highly effective in overcoming frictions in the interbank market. The findings in this article confirm, by and large, this presumption. In particular, long-term refinancing operations as well as asset purchase programmes can complement, or substitute for, changes in the key policy rate and ease financial conditions at a time when access to interbank credit might be restricted or excessively expensive. Reducing the need of recourse to such instruments in future crises, however, requires a more forceful convergence in the growth capacities of euro area economies, a task that lies beyond central bank mandates.

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Tobias Sebastian Blattner (corresponding author)
European Central Bank, Frankfurt am Main, Germany; email: tobias.blattner@ecb.europa.eu

Jonathan M. Swarbrick
Bank of Canada, Ottawa, Canada; email: jswarbrick@bankofcanada.ca

Postal address	60640 Frankfurt am Main, Germany
Telephone	+49 69 1344 0
Website	www.ecb.europa.eu

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