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Conference Paper

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Beiträge zur Jahrestagung des Vereins für Socialpolitik 2015: Ökonomische Entwicklung - Theorie und Politik - Session: Banks during the crisis, No. C03-V2

Provided in Cooperation with:

Verein für Socialpolitik / German Economic Association

Suggested Citation: Quint, Dominic; Tristani, Oreste (2015) : Liquidity provision to banks as a monetary policy tool: the ECB's non-standard measures in 2008-2011, Beiträge zur Jahrestagung des Vereins für Socialpolitik 2015: Ökonomische Entwicklung - Theorie und Politik - Session: Banks during the crisis, No. C03-V2, ZBW - Deutsche Zentralbibliothek für Wirtschaftswissenschaften, Leibniz-Informationszentrum Wirtschaft

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Liquidity provision to banks as a monetary policy tool: the ECB's non-standard measures in 2008-2011

February 28, 2015

Abstract

We study the macroeconomic consequences of the money market tensions associated with the financial crisis of 2008-2009. Our structural model includes the banking model of Gertler and Kyiotaki (2011) in the Smets and Wouters (2003) framework. We highlight two main results. First, a financial shock calibrated to account for the observed increase in spreads on the inter-bank market can account for one third of the observed, large fall in aggregate investment after the financial crisis of 2008. Second, the liquidity injected on the market by the ECB played an important role in attenuating the macroeconomic impact of the shock. In their absence, aggregate investment would have fallen much more—by between 50 and 70 percent. These effects are somewhat larger than estimated in other available studies.

1 Introduction

The Global financial crisis of 2007-08 was followed by a reduction of GDP of approximately 5 percent both in the euro area and in the United States. The GDP component most severely affected by the recession was aggregate investment, which fell by about 15-20 percent in both monetary areas. These developments motivated aggressive monetary policy responses, including the adoption of non-standard monetary policy measures with ensuing, sizable increases in the size of central banks' balance sheets. In the year following August 2008, the ECB balance sheet increased from 60 percent to over 120 percent of euro area GDP.

The type of non-standard measures adopted in the euro area are different from those implemented in the United States and by other major central banks. While the Federal Reserve purchased government bonds and mortgage backed securities, for example, the ECB measures took mostly the form of liquidity operations vis-a-vis banks.¹ The fragmentation of the euro area banking sector caused by the financial crisis produced severe malfunctionings, and at times a complete dry-up, of the interbank market. Asymmetric information and time-varying perceptions of counterparty risk made cash-rich banks unwilling to lend to banks with liquidity shortages. The latter banks, even if healthy and solvent, risked being forced into bankruptcy. Negative externalities on the real economy could thus be produced through a credit crunch or asset fire sales. The ECB interventions were tailored to address such money market malfunctioning. Large amounts of liquidity were provided to financial institutions, subject to adequate collateral, through various repo operations with different maturities.

The objective of our paper is to provide a quantitative assessment of the macro-economic impact of the ECB's non-standard measures. This assessment necessarily requires a structural model, because we wish to compute the counterfactual scenario that would have been observed, had non-standard measures not been implemented. We adopt a variant of the framework proposed by Gertler and Kiyotaki (2011), which includes an explicit characterisation of the interbank market—an obvious, minimum requirement to analyse the consequences of disruptions in such market. In the model, banks cannot rely exclusively on external finance, in the form of either retail deposits or deposits from other banks, because they have the temptation to embezzle assets.

¹Another difference, whose role we do not explore in this paper, has to do with the ECB's reliance on repo operations, rather than outright purchases.

This incentive problem produces a leverage constraint, so that banks are required to hold equity (or "have skin in the game"), and therefore charge a spread on loan rates to final borrowers.

In the model, at any point in time, banks whose customer firms have good investment opportunities will tend to borrow on the interbank market, while other banks will be net lenders. Under normal circumstances, we assume that the interbank market works frictionlessly and that banks do not attempt to appropriate funds from other banks. In a financial crisis, however, the temptation to embezzle assets financed through interbank loans increases. As a result, the incentive problem becomes more severe, the leverage constraint faced by borrowing banks becomes tighter, and all spreads increase. With the ensuing rise in lending rates, credit dries up and aggregate investment falls. In these circumstances, the provision of large amounts of liquidity by the central bank, even if at market interest rates, can reduce the adverse consequences of the crisis on investment. Central bank interventions allow liquidity-constrained banks to continue financing firms with good investment opportunities, even if cash-rich banks are unwilling to lend on the interbank market.

We assume that the financial crisis in the euro area amounted to a marked and persistent increase in banks' leverage constraint on the interbank market and that the ECB's non-standard measures were a reaction to such developments. We can therefore use the observed interbank market spreads and the amount of the ECB's liquidity providing operations to infer, through the lens of the model, the size of the underlying interbank market shock. We use this result to answer three related questions.

First, we investigate whether the interbank market shock, which was calibrated using only financial market prices, can account for a sizable share of the observed, large fall in aggregate investment after the financial crisis of 2008. We focus on investment because it is the component of the national accounts which was most heavily affected by the crisis. Our model suggests that the interbank market shock produced large real effects. In our benchmark specification of the ECB's rule for liquidity interventions, the shock accounts for over 30 percent of the fall in investment. It is conceivable that other disturbances—for example an increase in macroeconomic uncertainty, as argued by Bloom (2009)—contributed to the observed fall in aggregate investment during the great recession.

Given this result, we turn to our second question, which is to analyse the effectiveness

of the ECB's non-standard measures. In the model, we can switch off the central bank interventions and compute the resulting counterfactual scenario. The results of this exercise suggest that the effect of non-standard measures was sizable. In their absence, interbank spreads would have been at least 100 basis points higher and their adverse impact on investment would have been almost twice as severe.

Finally, we investigate the repercussions of the interbank market shock on inflation and find them to be negligible, so that no policy interest rate response is warranted through the Taylor rule. The main reason for this result is that, by construction in the model, lending spreads have no impact on households' consumption, so that consumption need not fall in response to the financial crisis. Our model would therefore require other shocks to account for inflation and policy rate developments during the Great recession.

Our paper fits into the recent literature which evaluates the non-standard policy measures implemented by central banks during the Great Recession. Using structural VAR models, Peersman (2011) and Boeckx et al. (2014) capture non-standard measures by looking at the expansion of the ECB balance sheet and studying its transmission effects. Affecting interest rate spreads of banks, the expansion of the balance sheet is effective in stabilizing the economy. Boeckx et al. (2014) further analyse how individual euro area countries were affected by these policies showing that the transmission was heterogeneous among member states. Other studies explicitly conduct a counterfactual exercise to evaluate the impact of the non-standard measures. Within a Bayesian VAR framework, Lenza et al. (2010) as well as Giannone et al. (2012) show that these policies had a significant effect in dampening the recession during the crisis.

As these studies rely on a reduced-form approach, closer to our approach are Fahr et al. (2014) as well as Cahn et al. (2014). Both papers use estimated DSGE models to evaluate the policy by the ECB during the recent crisis. The former uses a counterfactual exercise to focus on the unlimited supply of liquidity to banks at a fixed rate (so-called fixed-rate-full-allotment) as well as the effect of the expansions of maturities at which liquidity was provided (so-called long term refinancing operations). Since they apply the framework by Christiano et al. (2010) the model does not explicitly include a characterisation of the interbank market. Similar to our paper, Cahn et al. (2014) use the framework by Gertler and Kiyotaki (2011) to better capture the bank lending channel of the non-standard measures. However, they

solely focus on the macroeconomic effects of the long term refinancing operations.

Many other studies focus on the effects of the unconventional policy conducted in the US using a DSGE model. Amongst them, Gertler and Karadi (2013) show that this policy worked by replacing the private intermediation which broke down as financial markets froze up. Del Negro et al. (2011) attribute the effectiveness of the unconventional policies to the binding of the zero lower bound and the presence of nominal frictions. Christiano et al. (2015) conduct a counterfactual analysis focusing on how forward guidance dampened the effects of the recession.

The rest of the paper is organised as follows. Section 2 presents the model, which includes the banking sector of Gertler and Kiyotaki (2011) in the standard Smets and Wouters (2003) framework. We then describe our calibration in Section 3, with particular emphasis on the methodology that we use to filter out the interbank shock from the data. Our main results are presented in Section 4, starting from our estimates of the impact of the interbank shock on investment. In this section we also present our counterfactual scenario of no liquidity interventions by the ECB. Finally, we show that the interbank market shock might have had negligible impact on inflation and argue that other shocks would be necessary in our model to account for the observed development of inflation and the policy interest rate. We draw our conclusions in Section 5.

2 The Model

We rely on a general equilibrium model based on Smets and Wouters (2003) and augmented with a banking sector as in Gertler and Kiyotaki (2011).

The banking sector is composed of a retail and a wholesale market. The former market allows banks to raise deposits from households, while the latter is an interbank market where banks provide funding to each other. Both markets are characterised by an agency problem à la Gertler and Karadi (2011). Bankers can divert some of their bank's assets financed by either retail or wholesale deposits. These frictions give rise to spreads between the return on capital, the interbank market rate and the risk-free rate. The key difference between our model and Gertler and Kiyotaki's (2011) is that we allow for the frictions on the wholesale market to be time-varying in a stochastic fashion.

Banks invest into non-financial firms that differ in their opportunities to issue debt. In each period a given fraction of firms can issue new assets while the remaining fraction merely rolls over its existing debt. The opportunity to issue new assets arrives randomly to firms, but before the realization is known firms and banks already engage in a business relationship. We make this assumption for two reasons. First, such a framework is supposed to reflect a relationship-based financial system that predominates in Europe. Second, it creates the necessity of an interbank market. After the realization of investment opportunities, banks are either in short or abundant supply of liquidity depending on their business relationship with firms. This liquidity is traded in the interbank market.

In what follows, we only discuss the main structure of the model and describe all frictions in the economy. In the appendix, we present more detailed derivations.

2.1 Households

Each household consists of a given fraction of workers and bankers. Workers supply labor to the production sector while bankers manage financial intermediaries. Both agents transfer their earnings to their household and perfectly pool their consumption risk. Each period with a probability of $(1 - \sigma)$ a banker switches occupation and becomes a worker instead. The probability to switch occupation is independent of the duration agents have been bankers. Exiting bankers transfer the net worth they have accumulated during their term in office to their household. All exiting bankers are randomly replaced by workers, who will then become bankers. These new bankers obtain start-up capital from their household. While bankers are the owners of the financial intermediaries they manage, it is assumed that households place their deposits in banks belonging to other households. This assumption is needed to motivate the moral hazard problem introduced later. Households consume a non-durable consumption good C_t , provide labor to the intermediate goods sector L_t , for which they earn the nominal wage W_t , and have access to deposits D_t , which pay the nominal deposit interest rate R_t^N . They maximize the following utility function:²

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \xi_t \left[\log (C_t - hC_{t-1}) - \frac{(L_t)^{1+\varphi}}{1+\varphi} \right] \right\}, \quad (1)$$

²Since all households are identical, we do not make use of an additional subscript to differentiate between households.

where β stands for the discount factor, $h \in (0, 1)$ measures the influence of past consumption on utility and φ denotes the inverse elasticity of labor supply. Utility is furthermore affected by a preference shock ξ_t , which affects the discount rate of households and thus the intertemporal substitution. This preference shock follows an AR(1) process in logs:

$$\log(\xi_t) = \rho_\xi \log(\xi_{t-1}) + \varepsilon_{\xi,t}.$$

The budget constraint in nominal terms is given by:

$$P_t C_t + D_t \leq R_{t-1}^N D_{t-1} + W_t L_t + \Pi_t, \quad (2)$$

with P_t being the CPI-Index and Π_t being profits from the retail sector as well as transfers from exiting bankers net the start-up capital provided to new bankers.

2.2 Wage Setting

Following Smets and Wouters (2003) wages are assumed to be sticky. They are negotiated by labor unions which are subject to a Calvo (1983) scheme making wages adjust only sluggishly. For this purpose, households provide their homogenous labor services to labor unions, which differentiate these services and negotiate wages. Afterwards, unions sell the labor services to labor packers, which reassemble them into homogenous labor composites and offer them to intermediate goods producers. Unlike unions, these labor packers are assumed to be perfectly competitive.

Each period only a fraction $(1 - \theta_w)$ of wages can be re-negotiated by unions in the current period. As unions work on behalf of households, when negotiating wages they maximize the utility of households (1) subject to their budget constraint (2) and to the demand schedule of labor packers. Since wages are indexed to past inflation, the remaining fractions θ_w of wages are mechanically adjusted according to the CPI inflation of the last period. This indexation is however only partial, with $\chi_w \in (0, 1)$ controlling the intensity of the wage indexation.

2.3 Firms, Technology, and Nominal Rigidities

In each country four types of firms operate in the production sector. Intermediate goods producers combine labor and capital to produce intermediate goods which they sell to retailers. Retailers then differentiate these goods and sell them to the final goods producers. In the final goods sector retail goods are combined to consumption goods, which are then consumed by households. While intermediate and final goods producers operate under perfect competition and are able to adjust prices every period, there is monopolistic competition and staggered price setting à la Calvo (1983) in the retail sector. Capital goods are constructed by capital goods producers using consumption goods as sole input. Creating capital is subject to flow adjustment costs.

2.3.1 Intermediate Goods Producers

Intermediate goods producers fulfill two tasks in this model. They produce an intermediate good Y_t^M , which will be the sole input for producing the final good Y_t , and they finance the capital stock K_t used in production by selling assets to financial intermediaries. Intermediate firms differ in their investment opportunities. Each period a fraction γ^i of firms receives a signal allowing them to acquire new capital. The remaining fraction $\gamma^n = (1 - \gamma^i)$ of intermediate goods producers cannot change their capital stock. The signal to firms is assumed to be *iid* across time. All intermediate goods producers face an identical constant-returns-to-scale production function and we assume that labor is perfectly mobile across these firms. Therefore, we do not need to keep track of the distribution of capital across intermediate goods producers. Aggregate intermediate output Y_t^M can be expressed as a function of aggregate labor L_t and aggregate capital K_t :

$$Y_t^M = K_t^\alpha L_t^{(1-\alpha)}, \quad (3)$$

with α being the share of capital in the production function. The law of motion for the capital stock is given by the sum of newly acquired capital I_t by firms that received a signal allowing them to invest, the depreciated capital stock $\gamma^i (1 - \delta) K_t$ from last period of these firms, and the depreciated capital stock $\gamma^n (1 - \delta) K_t$ from

those firms that did not receive a signal in the current period:

$$\begin{aligned} K_{t+1} &= I_t + \gamma^i (1 - \delta) K_t + \gamma^n (1 - \delta) K_t \\ &= I_t + (1 - \delta) K_t. \end{aligned}$$

The parameter δ is the depreciation rate which is assumed to be identical for both types of intermediate goods producers.

Intermediate goods producers completely finance their capital acquisitions in advance by issuing assets. They sell these assets to the financial intermediary with which they have build up a business relationship at the beginning of each period. In contrast to financial intermediaries, intermediate goods producers face no constraints on obtaining funding. Using the capital stock as collateral the issued assets are claims against capital and since we assume no frictions in originating these assets, the asset price is equal to the price of one unit of capital. However, as we show in the appendix asset prices differ between the two types of firms. Let S_t^h be the claims issued by a firm of type h and Q_t^h the asset price of these claims, with $h = \{i, n\}$. The value of originated claims is then equal to the value of capital:

$$\begin{aligned} Q_t^i S_t^i &= Q_t^i [I_t + \gamma^i (1 - \delta) K_t], \\ Q_t^n S_t^n &= Q_t^n \gamma^n (1 - \delta) K_t. \end{aligned}$$

Since financing the capital stock is frictionless and intermediate goods producers issue perfectly contingent claims against their capital, these assets can either be interpreted as equity or perfectly state-dependent debt. Intermediate goods producers operate under perfect competition and earn zero profits. Each period they sell their products to retailers at a price of P_t^M and pay workers a nominal wage W_t . The gross return to capital can thus be expressed as:

$$Z_t = \frac{P_t^M Y_t^M - \frac{W_t}{P_t} L_t}{K_t},$$

which will be collected by financial intermediaries. The gross return Z_t can also be interpreted as a dividend paid to financial intermediaries.

2.3.2 Retailers

Retailers merely repackage intermediate goods. They do this at no cost and one unit of intermediate goods can be transferred into one unit of retail goods. In doing so they differentiate these goods and since retailers operate under monopolistic competition, each retailer h adds a mark-up to the marginal costs (given by the price of intermediate goods P_t^M) and sells its goods $Y_t^{\mathcal{R}}(h)$ at a price $P_t(h)$. Retail prices are assumed to be sticky with $1 - \theta$ being the probability that retailers can readjust prices in the current period. We also assume price indexation to past inflation so that the fraction θ of retailers, who do not adjust their prices in the current period, mechanically change their price according to last period's inflation. Retailers solve the following optimization problem:

$$\max_{P_t(h)} E_t \sum_{s=0}^{\infty} \theta^s \beta^s \Lambda_{t,t+s} \left\{ \left[\prod_{\tau=1}^s \left(\frac{P_{t+\tau-1}}{P_{t+\tau-2}} \right)^{\chi_P} \frac{P_t(h)}{P_{t+s}} - \frac{P_{m,t+s}}{P_{t+s}} \right] Y_{t+s}^{\mathcal{R}}(h) \right\}, \quad (4)$$

subject to future demand by final goods producers (equation 6). The parameter $\chi_P \in (0, 1)$ controls the intensity of the price indexation.

2.3.3 Final Goods Producers

Final goods producers aggregate the differentiated goods $Y_t^{\mathcal{R}}(h)$ they buy from domestic retailers according to the following CES function:

$$Y_t = \left[\int_0^1 Y_t^{\mathcal{R}}(h)^{\frac{\sigma-1}{\sigma}} dh \right]^{\frac{\sigma}{\sigma-1}}, \quad (5)$$

with σ being the price elasticity of retail goods. The cost minimization of final goods producers leads to the demand function for retail goods:

$$Y_t^{\mathcal{R}}(h) = \left(\frac{P_t(h)}{P_t} \right)^{-\sigma} Y_t, \quad (6)$$

where P_t is an aggregate of retail prices:

$$P_t = \left[\int_0^1 (P_t(h))^{1-\sigma} dh \right]^{\frac{1}{1-\sigma}}, \quad (7)$$

and which can be interpreted as the CPI index.

2.3.4 Capital Goods Producers

Capital goods producers provide new capital to the intermediate goods producers that received a signal allowing them to acquire new capital. They sell the new capital to these firms at the market price of Q_t^i . Creating capital is subject to flow adjustment costs so that capital goods producers solve the following profit maximization problem:

$$\max_{I_t} E_t \sum_{j=0}^{\infty} \beta^j \Lambda_{t,t+j} \left[(Q_t^i - 1)I_t - F \left(\frac{I_t}{I_{t-1}} \right) I_t \right]. \quad (8)$$

As in Christiano, Eichenbaum and Evans (2005) the cost function $F(\cdot)$ is convex ($F''(\cdot) > 0$) and adjustment costs are zero in the steady state ($F(1) = F'(1) = 0$). The stochastic discount factor $\beta^j \Lambda_{t,t+j}$ can be determined by the Euler equation of households.

2.4 Financial Intermediaries

Financial intermediaries channel funds from households to the production sector. They finance themselves through deposits collected from households and through retained earnings that they use to build up equity. Additionally, banks interact on an interbank market which allows intermediaries being short of liquidity to borrow from those having abundant liquidity. We introduce the necessity of an interbank market by assuming the following timing: At the beginning of each period banks and intermediary goods producers engage in a business relationship before these firms receive a signal on their ability to issue new assets. Based on the expected liquidity needs banks collect deposits from households. After this retail market has closed, firms receive a signal and either issue new assets or merely roll over their existing debt. Therefore, banks are either in short or abundant supply of liquidity. Since the interbank market opens after firms and banks know about their investment opportunities, this market allows financial intermediaries to manage their short-term liquidity needs, while the collection of deposits in this model should rather be understood as longer-term financing. Additionally to the interbank market, we introduce the possibility of liquidity provision by the central bank which we will later interpret as the non-standard policy tools used by the ECB after 2007.

Besides creating the necessity of an interbank market, the assumption on banks

and firms engaging in a business relationship before they have knowledge of their investment opportunities shall represent a banking-based financial system. Opposed to the US, financing of firms heavily depends on banks in the euro area. However, instead of assuming that a particular bank and firm never/only infrequently dissolve their relationship, we allow banks to choose with which intermediate goods producer they want to make business at the beginning of each period. To do so, they sell their existing claims to another bank in exchange for net worth. By doing so, ex-ante expected returns are equalized across banks at the beginning of each period. This mainly serves as a simplification, since due to such an arbitrage opportunity we do not need to keep track of the distribution of net worth across banks.

According to the aforementioned timing, after bank j has engaged in a business relationship, it decides on the amount of deposits D_{jt} it borrows from households. Next, after learning about its lending opportunity bank j decides on the amount of assets S_{jt}^h it buys for a given price Q_t^h , the amount of interbank borrowing B_{jt}^h (a negative value indicates that bank j offers liquidity on the interbank market) and on the amount of liquidity M_{jt}^h it borrows from the central bank. The subscript $h = \{i, n\}$ indicates whether a bank is engaged in a business relationship with a firm that is able to issue new assets ($h = i$), or whether a bank finances a firm that merely rolls over its debt ($h = n$). Notice that due to our assumption on the timing, the amount of deposits D_{jt} is independent of the type of banks, while everything else depends on the type indicated by the superscript h . The balance sheet of bank j thus reads:

$$Q_t^h S_{jt}^h = N_{jt}^h + D_{jt} + B_{jt}^h + M_{jt}^h,$$

with N_{jt}^h being the amount of net worth of bank j . Net worth is accumulated over time as the difference between earnings on assets $[Z_t + (1 - \delta) Q_t^h] S_{jt-1}$ and debt payments:

$$N_{jt}^h = [Z_t + (1 - \delta) Q_t^h] S_{jt-1} - R_{t-1} D_{jt-1} - R_{bt-1} B_{jt-1} - R_{mt-1} M_{jt-1},$$

where R_t , R_{bt} and R_{mt} are the real interest paid on deposits, interbank loans, and loans provided by the central bank, respectively. The gross returns on assets $[Z_t + (1 - \delta) Q_t^h]$ do not only include the dividend payment Z_t from intermediate goods producers, but also the resale value of assets $(1 - \delta) Q_t^h$, which depends on the type of bank. Due to financial frictions which will be introduced below, banks can expect a premium between the return on assets and the interest payments on

liabilities. Such a positive premium incentivizes the banker to accumulate assets and maximizes the value of the bank. Since bankers have to exit the market at the end of each period with probability $(1 - \sigma)$, the value of bank j is given by its expected terminal wealth:

$$V_{jt} = E_t \sum_{i=1}^{\infty} (1 - \sigma) \sigma^{i-1} \Lambda_{t,t+i} N_{jt+i}^h.$$

Financial frictions are introduced following the idea of Gertler and Karadi (2011). We assume an agency problem between financial intermediaries and its creditors as banks can divert a certain fraction of assets and transfer them to the household they belong to. When a banker diverts funds, the bank will be closed and the remaining fractions of assets serve as bankruptcy assets that are then distributed among creditors, i.e. depositors, the central bank as well as those banks holding interbank market claims against the defaulting bank. As in Gertler and Kiyotaki (2011) we assume that the degree of financial frictions differ among the two funding markets. Banks can divert assets financed by borrowing from depositors more easily than those financed by borrowing from other banks or the central bank. The way financial frictions are introduced results in an endogenous constraint on bank's ability to obtain funding. Creditors are only willing to provide funding to a bank as long as the banker has no incentive to divert assets. To ensure this, the value of the bank V_{jt} needs to exceed the gain a banker receives by diverting assets:

$$V_{jt} \geq \theta (Q_t^h S_{jt}^h - \omega_t B_{jt}^h - \omega_m M_{jt}^h). \quad (9)$$

According to the incentive constraint the value of the bank V_{jt} must exceed the fraction θ of assets which a banker can divert. As in Gertler and Kiyotaki (2011), ω_t and ω_m (with $\omega_t, \omega_m \in (0, 1)$) measure the possibility of diverting funds financed by interbank borrowing B_{jt}^h and by borrowing from the central bank M_{jt}^h , respectively. Values of 1 for either ω_t or ω_m imply that banks cannot divert assets financed by interbank borrowing or the liquidity provision by the central bank. Values below 1 imply that creditors would lose $(1 - \omega_t) B_{jt}^h$ and $(1 - \omega_m) M_{jt}^h$ of their claims in a bankruptcy.

While ω_m will be constant, we depart from Gertler and Kiyotaki (2011) and assume ω_t to be time-varying, following an AR(1) process in logs:

$$\log(\omega_t) = (1 - \rho_\omega) \bar{\omega} + \rho_\omega \log(\omega_t) + \varepsilon_{\omega,t}, \quad (10)$$

with $\bar{\omega}$ being the steady state of the shock and with $\varepsilon_{\omega,t}$ being the structural innovation to the shock. In this regard ω_t can be interpreted as measuring the confidence in the interbank market. In the policy exercise conducted in Section 4 we will use this parameter to simulate the confidence loss and the freezing up of the interbank market observed during the world financial crisis.

Every period, the fraction $(1 - \sigma)$ of bankers leaving the market are replaced by new bankers. This assumption is introduced to prevent the net worth of financial intermediaries to increase indefinitely. If bankers did not leave the market, they could accumulate enough equity to ensure that the incentive constraints (9) is never binding. When leaving the market, bankers transfer their net worth to the household they belong to. New bankers obtain start-up capital from their households proportional to the asset holdings of an exiting bank. We define aggregate net worth N_t^h for banks of type h as the sum of net worth of existing (old) banks N_{ot}^h and of new (young) banks entering the market N_{yt}^h :

$$N_t^h = N_{ot}^h + N_{yt}^h.$$

Net worth of existing banks is given by the difference of earnings from holding assets and interest payments on liabilities. As the mass of existing banks is σ and the mass of banks from type h is γ^h , aggregate net worth of existing banks is given by:

$$N_{ot}^h = \sigma \gamma^h \{ [Z_t + (1 - \delta) Q_t^h] S_{jt-1} - R_{t-1} D_{jt-1} - R_{mt-1} M_{jt-1} \}.$$

We assume that entering banks obtain a fraction $\xi / (1 - \sigma)$ of the asset holdings of an exiting bank. Net worth of new banks is then given by:

$$N_{yt}^h = \xi \gamma^h [Z_t + (1 - \delta) Q_t^h] S_{jt-1}.$$

Notice that due to the aggregation interbank market loans cancel out in both definitions. Finally, the aggregate balance sheet for the entire banking sector obeys:

$$Q_t^i S_t^i + Q_t^n S_t^n = N_t^i + N_t^n + D_t + M_t^i + M_t^n.$$

2.5 Closing the Model

To close the model we impose market-clearing conditions for the goods market and define policy rules for the conventional monetary policy as well as the non-standard measures.

2.5.1 Market Clearing

In the labor market, the intermediate goods sector as well as the retail goods sector supply has to be equal to demand. In the final goods sector output is equal to the demand of households, the demand for investment goods from capital producers, and the investment adjustment costs:

$$Y_t = C_t + I_t + F \left(\frac{I_t}{I_{t-1}} \right) I_t. \quad (11)$$

2.5.2 Central Bank Policies and Interest Rates

Monetary policy is conducted by the central bank with an interest rate rule that targets CPI inflation and real output growth. Following Smets and Wouters (2003), we introduce Taylor-type rule prescribing that the nominal policy rate R_t^N reacts to the lagged interest rate, inflation, the growth rate of inflation, the output gap (which we proxy as deviation of real output from its steady state) as well as the growth rate of the output gap:

$$\frac{R_t^N}{R^N} = \left(\frac{R_{t-1}^N}{R^N} \right)^{1-\gamma_R} \left[\left(\frac{P_t}{P_{t-1}} \right)^{\gamma_\pi} \left(\frac{P_t}{P_{t-1}} / \frac{P_{t-1}}{P_{t-2}} \right)^{\gamma_{\Delta\pi}} \left(\frac{Y_t}{Y} \right)^{\gamma_Y} \left(\frac{Y_t}{Y} / \frac{Y_{t-1}}{Y} \right)^{\gamma_{\Delta Y}} \right]^{\gamma_R}. \quad (12)$$

The relationship between the nominal and the real risk-free interest rate is given by the Fisher equation:

$$R_t^N = R_t E_t \pi_{t+1}.$$

A monetary policy rule as in equation (12) is standard in the literature and known to describe well actual policy interest rate levels over the decades before the financial crisis. For our results, we also need to specify a rule followed by the central bank to inject liquidity in the market. Given the unprecedented nature of these non-standard monetary policy measures, we cannot rely on existing results in the literature. Given the different types of measures adopted by the ECB over the years

after the crisis, even the choice of non-standard "monetary policy instrument" is controversial. On the one hand, one may argue that the actual non-standard monetary policy instrument was the interest rate on ECB loans to banks, R_m , because the quantity of liquidity provided by the ECB was by and large demand-driven at the MRO interest rate set by the central bank. On the other hand, one may argue that the actual interest rate on ECB liquidity was larger than the MRO, since such loans were conditional on the provision of it adequate collateral. Given the difficulty to compute the true cost of ECB liquidity—given by the sum of R_m and the opportunity cost of pledged collateral—a non-standard policy rule specified in terms of the quantity of liquidity could thus be more appropriate.

Given that the size of the ECB balance sheet was the most apparent sign of the implementation of non-standard monetary policy measures, it may also have been the key market indicator of the strength of its non-standard intervention. In this paper, we therefore specify the non-standard monetary policy rule directly in terms of the size of liquidity injected by the ECB. Given the importance of the rule to form expectations on the future evolution of non-standard measures, we explore the implications of two different assumptions.

In the first case, liquidity injections relative to GDP follow an exogenous AR(1) process:

$$\log(\mathcal{M}_t) = \rho_M \log(\mathcal{M}_{t-1}) + \varepsilon_{M,t}, \quad (13)$$

This specification is based on the assumption that markets could not anticipate the ECB intervention, even after observing the increase in money market spreads. The ECB injections were therefore a surprising measures. Given the outstanding amount of liquidity at any point in time, however, equation (13) assumes that markets would understand that such liquidity would only be withdrawn slowly. This justifies that persistent coefficient ρ_M .

The alternative specification assumes that liquidity injections relative to GDP were related to the interbank market spread

$$\log(\mathcal{M}_t) = \rho_M \log(\mathcal{M}_{t-1}) + \gamma_{R^b} \log\left(\frac{R_t^b}{R_t} / \frac{R^b}{R}\right) + \varepsilon_{M,t}. \quad (14)$$

In this case the market would anticipate the ECB intervention given the widening of interbank spreads. As in the previous case, equation (14) also assumes that liquidity

injections are persistent, so that they would be withdrawn slowly even in the face of a narrowing of spreads.

3 Calibration and Conditioning of Variables

To study the effects of the financial crisis on the euro area economy, we adopt the following research strategy. We first assume that the trigger of the increase in money market spreads observed as of the second half of 2007 can be captured through a tightening of the funding constraint on the interbank market, that is a negative ω_t shock. Given this assumption, and given the non-standard monetary policy response of the ECB, we can use our model to filter out a time series for ω_t , from the observed time series of interbank market spreads and from the liquidity provision by the ECB.

Given the structural shock ω_t , we can then compute its effect on all endogenous variables and compare them with their empirical counterparts to evaluate how much of the Great recession is due to the interbank market tensions. Furthermore, we can study policy counterfactuals, i.e. analyse the implications of interbank market disruptions in the absence of the non-standard policy.

Note that this approach treats the innovations in the interbank market spread and in the ECB's reaction functions as ex-ante unknown to agents. This is an arguably realistic assumption, given the unprecedented nature of the crisis.

In the rest of this section we provide further details on our parameter calibration and on our simulation strategy.

3.1 Calibration

We mainly follow Smets and Wouters (2003) for calibrating the parameters associated with the real economy. Parameter values for the financial sector are taken from Gertler and Kiyotaki (2011). The calibration is summarized in Table 1. We set the discount factor of households to $\beta = 0.99$, which implies an annual risk-free interest rate of 4 percent. The capital share in production is equal to $\alpha = 0.3$ and we set the depreciation rate to $\delta = 0.025$, assuming an annualized depreciation rate of 10 percent. Smets and Wouters (2003) estimate for the euro area a habit for-

mation parameter³ of $h = 0.592$ and an inverse Frisch elasticity of labor supply of $\varphi = 2.503$. We do not follow these authors when calibrating the investment adjustment cost parameter η . Since their model does not include financial frictions, they obtain a rather high parameter. As financial frictions in our model already restrain producers in their ability to invest, we rather follow Gertler and Kiyotaki (2011) and set $\eta = 1.5$. Smets and Wouters (2003) estimate the probability of being able to adjust prices and wages to be equal to $\theta_p = 0.905$ and $\theta_w = 0.742$, respectively. The indexation of prices and wages is equal to $\chi_p = 0.477$ and $\chi_w = 0.728$, respectively. We set the elasticity of substitution between retail goods to $\varepsilon_y = 10$ and between labor to $\varepsilon_l = 3$. This implies a price mark-up of 10 percent and a wage mark-up of 50 percent. The persistence of the preference shock is $\rho_\xi = 0.838$.

Following Gertler and Kiyotaki (2011) we assume that 25 percent of firms receive a signal allowing them to adjust their capital stock ($\gamma^i = 0.25$) and that on average bankers are in office for 10 years ($\sigma = (40 - 1) / 40$). The transfer to entering bankers ξ as well as the fraction of divertable assets θ are calibrated to allow for an average leverage ratio of 4 and an annualized spread between the return to capital and the risk-free interest rate of 100 basis points. We assume that in the steady state interbank market frictions are negligible and calibrate the average degree of interbank market frictions to $\bar{\omega} = 0.99$. Setting the parameter not equal to unity has practical reasons. As shown by Gertler and Kiyotaki (2011) with frictionless interbank markets ($\omega_t = 1$) the model simplifies to the framework of Gertler and Karadi (2011), making the differentiation between banks irrelevant. In such a setting, all banks are balance sheet constrained. However, under our calibration, with imperfect interbank markets ($\omega_t < 1$) only banks which have the opportunity to invest in new assets are constraint. Financial intermediaries which have no investment opportunities in the current period are not balance sheet constraint. Instead, their funds exceed their investment opportunities so that their expected excess return on assets over deposits is zero. They are therefore willing to provide liquidity to other banks in the interbank market. For this reason, we do not allow the degree of interbank market frictions ω_t to increase to 1 in our exercise. Finally, Smets and Wouters (2003) estimate the inflation coefficient and the inflation growth coefficient in the Taylor rule to be $\gamma_\pi = 1.688$ and $\gamma_{\Delta\pi} = 0.151$, respectively. The coefficients for the output gap and the growth in the output gap are $\gamma_y = 0.098$ and $\gamma_{\Delta y} = 0.158$, respectively. The inertia parameter is $\gamma_R = 0.956$.

³Smets and Wouters (2003) actually use external instead of internal habit formation.

The calibration of the persistence of the confidence shock as well as of the non-standard policy rule is more challenging, since we cannot rely on the existing literature. We therefore estimate these parameters from simple, reduced-form regressions. More specifically, we estimate an AR(1) model on the interbank market spread and assume that its persistence corresponds to the persistence of the ω_t shock. This procedure yields $\rho_\omega = 0.87$. Similarly, we calibrate the parameters of the non-standard monetary policy rule based on an estimation of either equation (13) using the time series of ECB liquidity injections, or equation (14) using both the ECB liquidity injections and the interbank market spread. This procedure yields $\rho_M =$ for the exogenous non-standard policy rule and $\rho_M = 0.94$ and $\gamma_{R^b} = 26.2$ for the endogenous non-standard rule. As a robustness check, we will also run our simulations using perturbed parameter values, where the perturbations are equal to plus or minus a multiple of the standard deviation of the above estimates.

3.2 Conditioning of Variables

We solve the model by doing a first-order Taylor approximation to the equilibrium conditions around the deterministic steady state of the model and applying a generalized Schur decomposition. The solution can then be expressed in first order state-space form:

$$\mathbb{Y}_t = \mathbb{A}\mathbb{Y}_{t-1} + \mathbb{B}\mathbb{U}_t, \quad (15)$$

with \mathbb{Y}_t containing all endogenous variables and \mathbb{U}_t being a vector of structural shocks. The matrices \mathbb{A} and \mathbb{B} are functions of the structural parameters of the model.⁴ We will partition the vector of endogenous variables:

$$\mathbb{Y}_t = \begin{bmatrix} \mathbb{Y}_t^C \\ \mathbb{Y}_t^U \end{bmatrix},$$

with \mathbb{Y}_t^C being a vector of m variables whose realisations can be used to back out m shocks \mathbb{U}_t and \mathbb{Y}_t^U containing all other endogenous variables. We condition the path of \mathbb{Y}_t^C for T periods starting from $t = 0$, when we assume that all variables are at their steady state.

Define the path of realisations of \mathbb{Y}_t^C at times $\tau \in (1; T)$ as \mathbb{X} , where at any point in time \mathbb{X}_τ is a vector of size m . the path of structural shocks that implies the

⁴We use Dynare for solving and simulating the model.

restricted path of conditioned variables. At any point in time, define $\mathbb{U}_{\tau|\mathbb{X}}$ as the path of \mathbb{U}_t , given \mathbb{X}_τ . Using the first order state-space representation (15) of the model, we can derive $\mathbb{U}_{\tau|\mathbb{X}}$ as:

$$\mathbb{U}_{\tau|\mathbb{X}} = \tilde{\mathbb{B}}^{-1} \left[\mathbb{X}_\tau - \widetilde{\mathbb{A}}\mathbb{Y}_{\tau-1|\mathbb{X}} \right]. \quad (16)$$

The matrix $\tilde{\mathbb{B}}$ is a submatrix with the first $(m \times m)$ elements of \mathbb{B} and the vector $\widetilde{\mathbb{A}}\mathbb{Y}_{\tau-1|\mathbb{X}}$ includes only the first m elements from the product $\mathbb{A}\mathbb{Y}_{\tau-1|\mathbb{X}}$.

Once we have filtered out the path $\mathbb{U}_{\tau|\mathbb{X}}$ of m shocks, we can compute the contribution of these shocks to the historical realisation of all variables in our model. We simply need to cumulate the impact of these m shocks through equation (15):

$$\begin{aligned} \mathbb{Y}_{1|\mathbb{X}} &= \mathbb{A} \underbrace{\mathbb{Y}_{0|\mathbb{X}}}_{=0} + \mathbb{B}\mathbb{U}_{1|\mathbb{X}} = \mathbb{B}\mathbb{U}_{1|\mathbb{X}}, \\ \mathbb{Y}_{2|\mathbb{X}} &= \mathbb{A}\mathbb{Y}_{1|\mathbb{X}} + \mathbb{B}\mathbb{U}_{2|\mathbb{X}} = \mathbb{A}\mathbb{B}\mathbb{U}_{1|\mathbb{X}} + \mathbb{B}\mathbb{U}_{2|\mathbb{X}}, \\ \mathbb{Y}_{3|\mathbb{X}} &= \mathbb{A}\mathbb{Y}_{2|\mathbb{X}} + \mathbb{B}\mathbb{U}_{3|\mathbb{X}} = \mathbb{A}^2\mathbb{B}\mathbb{U}_{1|\mathbb{X}} + \mathbb{A}\mathbb{B}\mathbb{U}_{2|\mathbb{X}} + \mathbb{B}\mathbb{U}_{3|\mathbb{X}}, \\ &\vdots \\ \mathbb{Y}_{\tau-1|\mathbb{X}} &= \mathbb{A}^{\tau-2}\mathbb{B}\mathbb{U}_{1|\mathbb{X}} + \mathbb{A}^{\tau-3}\mathbb{B}\mathbb{U}_{2|\mathbb{X}} + \dots + \mathbb{A}\mathbb{B}\mathbb{U}_{\tau-2|\mathbb{X}} + \mathbb{B}\mathbb{U}_{\tau-1|\mathbb{X}}. \end{aligned} \quad (17)$$

In our paper, the crisis is driven by a disruption in the interbank market due to a loss in confidence among financial intermediaries. The central bank reacts to this by significantly increasing its supply of liquidity to financial intermediaries. We thus use as conditioning variables both the spread between the interbank rate and the risk free rate R_{bt}/R_t , and the amount of liquidity \mathcal{M}_t injected by the central bank to back out innovations to the confidence shock (10) as well as the non-standard policy rule (given either by equation 13 or 14).

4 Simulating the Financial Crisis in the Euro Area

In August 2007 tension in the European (as well as in the US and UK) money market emerged. Spreads between secured and unsecured money market rates spurred and transaction volumes declined significantly. The interbank market spread—measured as the difference between the 3-month EURIBOR and the 3-month overnight interest swap (OIS) rate—was quoted at 8 basis points on average before the crisis, but it

increased by more than 60 basis points in 2007q3. These developments were followed by an increase in lending spreads—measured as the difference between the interest rates on loans to non financial corporations for up to one year and the 3-month overnight interest swap (OIS) rate—by an equivalent amount.

The filing for bankruptcy of Lehman Brothers in September 2008 aggravated the crisis. The interbank market spread doubled reaching almost 120 basis points by the end of 2008. This led to a severe breakdown of this market and triggered a recession apparent from the surge of the lending spread by more than 200 basis points in 2008q4 as well as the drop in investment. The decrease in investment was more persistent than the surge in interest rates reaching between -10 and -20 percent by the end of 2010. The response by the ECB included an unlimited supply of liquidity to banks at a fixed rate (the so-called fixed rate full allotment), significant changes in the requirements for collateral and the expansion of maturities at which liquidity was offered (so-called long-term refinancing operations). These measures resulted in an increase of liquidity provided to euro area banks by 350 billion euro right after the bust of Lehman Brothers (corresponding to 15 percent of euro area GDP). Until 2011 these non-standard measures ranged between 10 and 20 percent of GDP.⁵

In this section, we study the financial crisis and its macroeconomic consequences through the lens of our model. We begin with an account of the macroeconomic consequences of the opening up of interbank spreads in 2007 and 2008. We show that the interbank market shock alone can explain a non-negligible proportion of the marked fall in investment recorder during the Great recession. We then assess the effect of the ECB's non-standard measures through a counterfactual simulation. Our results suggest that, absent the ECB's intervention, interbank spreads would have increased much more, lending spreads would have soared, and investment would have fallen even more markedly. One striking feature of our simulations is that inflation and, consequently, the standard policy interest rate are not significantly affected by the financial market shock. We therefore analyse next whether an additional demand-type shock can account for the observed dynamics of inflation and the policy interest rate. All in all we find that the combination of an interbank market shock and a demand shock can account for most of the macroeconomic developments observed over the Great recession.

⁵Lenza et al. (2010) provide an overview how the ECB reacted to the financial crisis and compare its non-standard measures with the policies conducted by the US Federal Reserve and the Bank of England.

For our analysis, we find it useful to identify two phases of the financial crisis in Europe: first, the financial turmoil of 2007q3-2008q3 followed by the bankruptcy of US investment bank and an interbank market crisis which stretched well into 2009; second, the European debt crisis which started in 2010 and intensified over 2011, as financial markets called the solvency of several euro area countries more and more into question. Our main focus is on the first period. Nevertheless, in a last subsection we also explore the ability of our model to account also for macroeconomic developments following the sovereign debt crisis. The nature of the sovereign debt crisis is obviously different from that of the global financial crisis of 2007 and 2008, but the sovereign debt crisis also had spillovers on banks, which could be captured by our model. Our results confirm this conjecture, but only at the cost of overstressing the model's mechanics.

4.1 Accounting for the Financial Crisis

As mentioned above, we account for the increase in interbank market spreads through an interbank market shock ω_t , which is the main focus of our analysis. We extract this shock jointly with a non-standard monetary policy shock $\varepsilon_{M,t}$ to condition our results on the ECB's non-standard measures. We subsequently study the additional consequences of a consumer preference shock ξ_t . In practice, we extract all three shocks at the same time using data on consumption, interbank market spreads and the ECB's non-standard measures.

We need three observable variables to back out the shocks from the data. We use the interbank market spread, the ECB's non-standard liquidity operation, and aggregate consumption. More precisely, we assume that the policy rate R_t in the model corresponds to the 3-month OIS rate, which is the interest rate at which solvent banks could exchange liquidity over the crisis period. The interbank lending rate R_t^b is instead proxied by the 3-month EURIBOR. These variables therefore define the interbank market spread R_t^b/R_t . The model's lending rate $R_{K,t}$ is captured by the interest rates on loans to non financial corporations for up to one year.⁶ The lending spread $R_{K,t}/R_t$ is in deviation from three-month OIS rate. Finally, we measure the ECB's non-standard liquidity operation with the size of the assets on

⁶Our lending rate $R_{K,t}$ is actually a weighted average of the gross return on new investments $R_{K,t}^i$ and the gross return on existing debt which is rolled over $R_{K,t}^n$. However, the picture will not change if we use data on outstanding loans as both rates behaved very similar over our sample.

the ECB's balance sheet held "for monetary policy purposes".⁷

The solid lines in Figure 1 show the impact of the financial shock ω_t over the period from the 2007q2 to 2010q4. Specifically, we report the model implied values of investment, the ECB's liquidity injections, the interbank market spread and the spread between lending rates and policy rates (solid lines). Given our uncertainty as to the perceived persistence of the financial shock ρ_ω , we also simulate the model under higher and lower values of ρ_ω . We use the values $\rho_\omega = (0.83, 0.91)$, which is the interval around the estimated parameter of one half standard deviation (see section 3.1). The simulations under the different values of ρ_ω are shown as the dark grey shaded areas around the solid lines. Finally the figure depicts the change in the data relative to 2007q3 (dashed line). Note that the match between the model and the data occurs by construction for the ECB's liquidity injections and the interbank market spread.⁸

The simulated change in the lending spreads following the financial shock ω_t gives us an idea of the model's ability to capture well the transmission of the shock through the banking sector. The bottom right chart in Figure 1 suggests that our model is quite successful in this respect. The model-implied increase in lending spreads $R_{K,t}/R_t$ is consistent with actual developments in corporate funding conditions. Both are strongly influenced by the dynamics of the interbank spread. They increase at the end of 2007, then again, and more markedly, after the Lehman bankruptcy reaching a peak of around 2 percentage points in 2008q4, and they come down slowly over 2009 and 2010 to values around 1%.

Given this good fit of the dynamics of lending rates, we can now assess the financial shock's implications on aggregate investment in the top right chart of Figure 1. The fall in investment is sizable. It starts edging down already during the financial turmoil in 2007 and then falls persistently down to a trough of between 2 and 6 percentage points. Somewhat surprisingly, the fall in investment is more marked when the shock is expected to be less persistent. The reason is that, *ceteris paribus*, a shock with lower persistence would generate a smaller increase in interbank spreads. Matching the observed increase in interbank spreads, therefore, requires a larger size of the ω_t shock, the lower its persistence. In turn, a larger, adverse financial shock

⁷These operations exclude any liquidity injections carried out for lender of last resort reasons.

⁸As we do not show the influence of the preference shock, the path for the interbank market spread does not perfectly reproduce the data. The very small difference between model and data suggests however that the role of the preference shock on interbank variables is negligible.

causes a more marked fall in investment.

Assessing whether the model-implied fall in investment is comparable to actual outcomes requires one to take a stand on the trend in investment. For investment Figure 1 reports not only the raw data (the dashed line), but also a light grey shaded area corresponding to different assumptions on the investment's trend. We consider two alternatives measures of the trend in investment, derived either from the HP-Filter (over the sample 1999q1-2014q3) or by estimating a linear pre-crisis trend (over the sample 1999q1-2007q2).⁹ The shaded area represents deviations from these two trends normalized to be zero in 2007q2. All in all, our model accounts for a sizable share of the actual drop in actual investment. Depending on the different assumptions about trend investment, the share varies between one half and one third. This confirms the hypothesis that the financial crisis was a major determinant of the Great recession. One reason why the recession in our model is not as severe as in the data may be the absence of an explicit residential as well as a public sector in our model. Since some countries experienced a large boom-bust cycle in housing, the drop in investment in the euro area was indeed driven to a large extent by the weakening in residential as well as public investment. Another possibility is that the financial crisis was accompanied by an adverse demand shock. We investigate this possibility in more detail in section 4.3.

Figure 2 repeats the exercise of Figure 1 under the assumption of a non-standard policy rule with an endogenous reaction to interbank market spreads, i.e. equation (14). The new results correspond to the thick dashed line. The results from Figure 1 are also reported for comparison (thick solid line). The key take away from Figure 2 is that our results are robust to changes in the assumption about the non-standard policy rule. Specifically, the implications of the financial shock on lending spreads are very similar. The fall in investment is somewhat slower, but more persistent, which is more in lined with the data.

We can conclude that our simple model, which includes a financial sector consisting of a corporate lending and an interbank lending market, is able to replicate well the spillovers of money market tensions on lending conditions during the crisis. The model suggests that the increase in lending rates explained a sizable portion of the fall in investment that occurred during the Great recession.

⁹The latter approach is also taken by Christiano et al. (2015).

4.2 Counterfactual: What if the ECB had not intervened?

Our results in Figures 1 and 2 are conditional on the ECB's non-standard monetary policy measures. What would have been the macroeconomic effect of the financial shock if the ECB had not implemented its non-standard policy? To answer this question we now do a counterfactual analysis in which we set to zero all monetary injections implied by either equation (13) or equation (14).

Focusing on the pre-Lehman period and especially the Lehman period, the recession in the euro area would have been much more severe without the non-standard measures implemented by the ECB. Especially, after the Lehman bust, the provision of liquidity to the financial sector, helped to dampen the effect of the crisis on interest rates and via this on the real economy. Based on the exogenous non-standard policy rule (Figure 3) the money market spread would have been 100 basis point higher in 2008q4. This would have translated into an increase in lending spreads by 120 basis points. The fall in investment would have been 70 percent more severe. Compared to the 3.5% drop in the benchmark, investment would have fallen by almost 6% in the absence of ECB intervention.

The counterfactual fall in investment would have been even larger under our alternative calibrations of the persistence of the confidence shock ω_t . The dark grey-shaded areas report the counterfactual results using the values $\rho_\omega = (0.83, 0.91)$. They suggest that investment would have fallen by up to a maximum of 8.5 percent in 2009q2.

The counterfactual scenario is even more severe when using the feedback policy rule (Figure 4). The fall in investment would have been 100 percent larger in the absence of non-standard measures, reaching a trough of over 2009.

All in all, our results suggest that the non-standard measures implemented by the ECB had a powerful role in attenuating the real consequences of the financial crisis, possibly more powerful than in other available studies.

For example, Fahr et al. (2013) also evaluates the impact of the non-standard measures using a DSGE model. However, differently from our approach here, that paper focuses jointly on all structural shocks which can account for developments over 2008-2010. Moreover, Fahr et al. (2013) concentrates on some specific ECB measures, namely the fixed rate full allotment policy and the long-term refinancing operations. Finally, the counterfactual scenario in Fahr et al. (2013) is implemented in terms of the implications it produces on the standard rule for the policy interest

rate. Given all these differences, Fahr et al. (2013) finds that GDP would have been lower by approximately 25 percent, had the ECB not implemented the fixed rate full allotment policy.

Other available studies rely on a reduced-form framework. Lenza et al. (2010) compute a counterfactual analysis within a Bayesian VAR through a conditional forecast, where the conditioning assumption is that money market spreads would have stayed at the elevated levels observed in October 2008. The authors find that non-standard measures affect the macroeconomy mainly via its impact on spreads but have a positive effect only with a delay of several month. Lenza et al. (2010) report a lower fall in industrial production between 1.0 and 2.5 percentage points, due to the intervention by the ECB. This compares to the 13% maximum fall in euro area industrial production (excluding construction) during the Great recession. Giannone et al. (2012) shows that the non-standard measures had a large impact on the wholesale funding opportunities of financial institutions. These policies eased funding conditions especially for institutions that do not have direct access to central bank liquidity (like insurance companies, pension funds, and money market funds). Through this channel, the ECB measures reduced the fall in industrial output by approximately 2 percent in 2011.

4.3 The Great recession and inflation

In this section we study the consequences of the interbank market shock on other macro variables.

Figure 5 shows that consumption, inflation and the policy interest rate remain essentially unchanged over the simulation horizon. Given the stable dynamics of consumption, and in spite of the fall in investment, GDP only decreases slightly. This is in contrast with actual developments in these variables. Especially GDP and the policy interest rate fell markedly over the simulation period.

Our model therefore identifies a relatively stark separation between standard and non-standard monetary policy interventions. Non-standard measures are targeted to the financial shock and prevent a larger fall in investment. Standard interest rate cuts would be necessary to prevent a deflationary scenario. Such scenario would arise as a result of an additional shock of the demand type.

One important caveat for this conclusion is that the lack of sensitivity of aggregate

consumption to the interbank shock partly occurs by construction in our model. The reason is that households do not need bank financing for their consumption expenditures.

5 Conclusions

To be written

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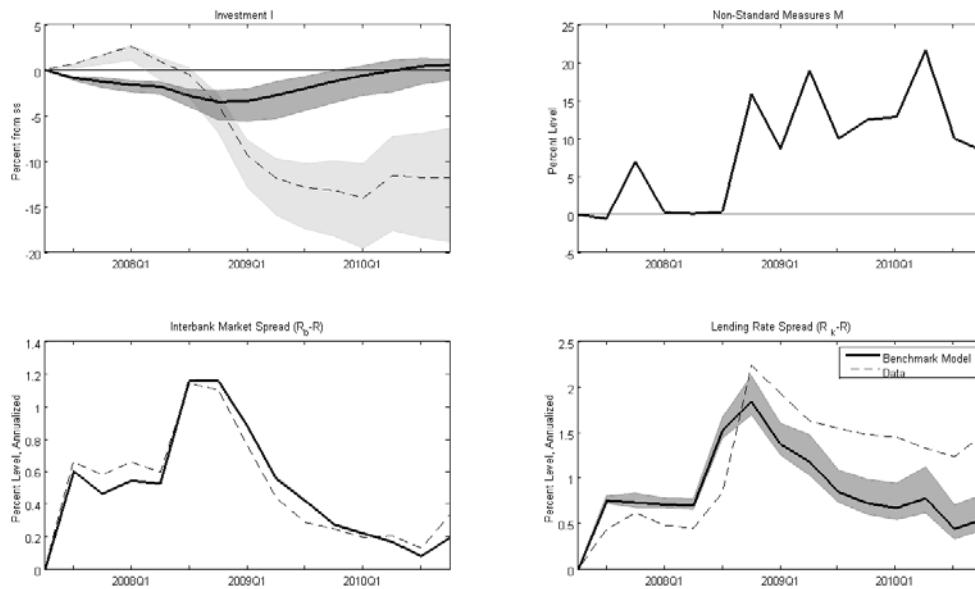
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Table 1: Baseline Calibration

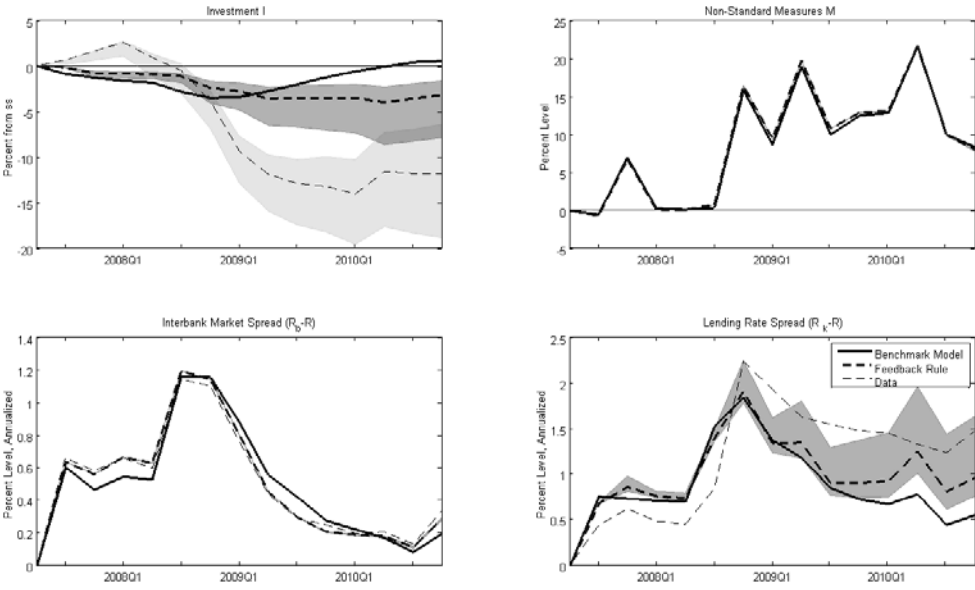
Households		
β	0.990	discount factor
h	0.592	habit parameter
φ	2.503	inverse Frisch elasticity
ρ_ξ	0.838	persistence parameter preference shock
Non-Financial Sector		
α	0.300	capital share
δ	0.025	depreciation rate
η	1.500	inverse elasticity of net investment to the price of capital
θ_p	0.905	Calvo probability prices
χ_p	0.477	indexation of prices
θ_w	0.742	Calvo probability wages
χ_w	0.728	indexation of wages
ε_y	10.00	elasticity of substitution between retail goods
ε_l	3.000	elasticity of substitution between labor
Financial Sector		
γ^i	0.250	fraction of firms with investment opportunities
σ	0.972	survival rate of bankers
ξ	0.002	transfer to entering bankers
θ	0.408	fraction of divertable assets
$\bar{\omega}$	0.990	average degree of interbank market frictions
ω_g	0.990	fraction of non-divertable central bank assets
ρ_ω	0.870	persistence parameter confidence loss
Government		
γ_π	1.688	Taylor rule inflation coefficient
$\gamma_{\Delta\pi}$	0.151	Taylor rule inflation growth coefficient
γ_y	0.098	Taylor rule output gap coefficient
$\gamma_{\Delta y}$	0.158	Taylor rule output gap growth coefficient
γ_R	0.956	Taylor rule smoothing parameter
ρ_M	0.940	persistence parameter non-standard policy

Figure 1: Impact of the Financial Shock under the Exogenous Non-Standard Policy Rule, 2007q2-2010q4



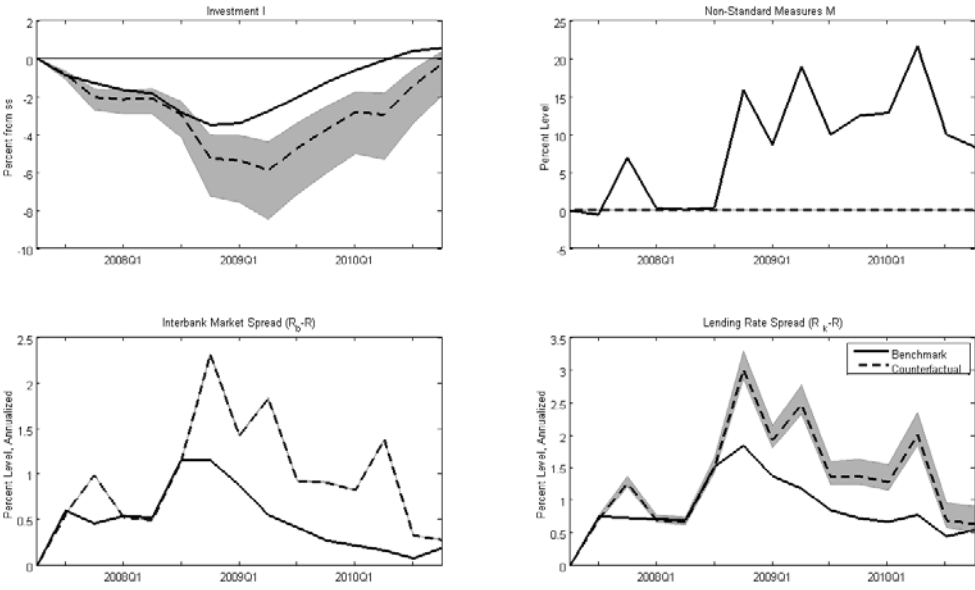
NOTE: In each panel the thick solid line indicates the impact of the financial shock under the exogenous non-standard policy rule (13). The thin dashed line indicates history. For investment the thin dashed line indicates the raw data (where the trend of the series is not taken into account). The light grey shaded area indicates deviations from trend which is derived either from the HP-filter or by estimating a linear pre-crisis trend. All data is normalized to be zero in 2007q2. The dark grey shaded area indicates different values for the persistence of the financial shock.

Figure 2: Impact of the Financial Shock under the Feedback Non-Standard Policy Rule, 2007q2-2010q4



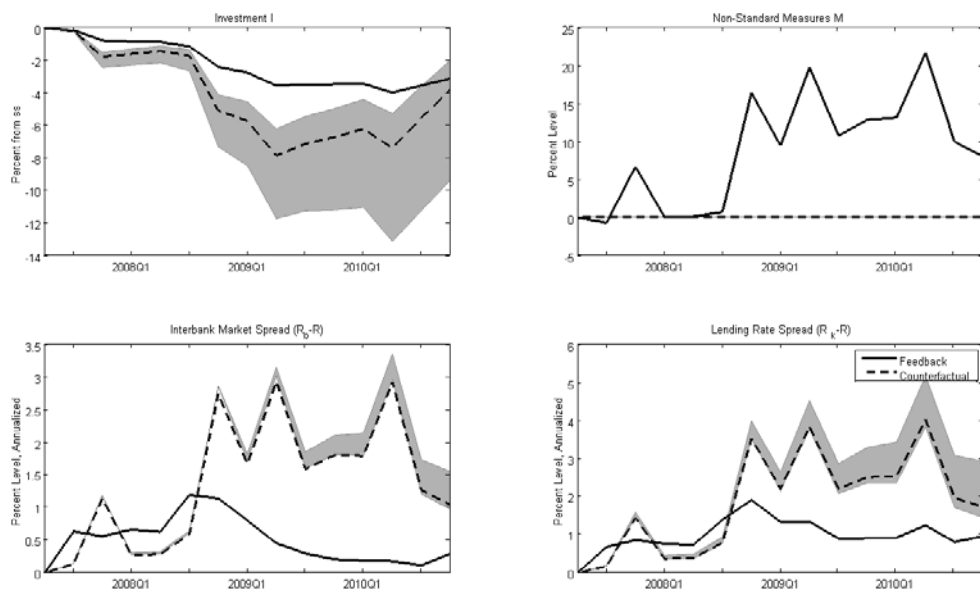
NOTE: In each panel the thick dashed line indicates the impact of the financial shock under the feedback non-standard policy rule (14), which reacts to the interbank market spread. Results from Figure 1 are also reported for comparison (thick solid line). The thin dashed line indicates history. For investment the thin dashed line indicates the raw data (where the trend of the series is not taken into account). The light grey shaded area indicates deviations from trend which is derived either from the HP-filter or by estimating a linear pre-crisis trend. All data is normalized to be zero in 2007q2. The dark grey shaded area indicates different values for the persistence of the financial shock.

Figure 3: Counterfactual Analysis using the Exogenous Non-Standard Policy Rule, 2007q2-2010q4



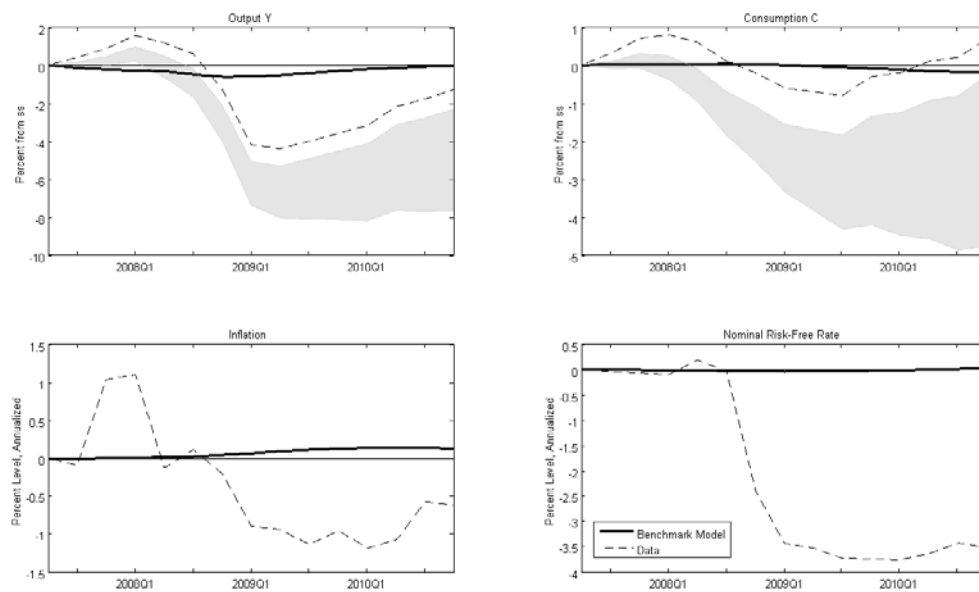
NOTE: In each panel the solid line indicates the impact of the financial shock under the exogenous non-standard policy rule (13). The dashed line indicates the counterfactual in which all monetary injections are set to zero. The dark grey shaded area indicates the counterfactual results using different values for the persistence of the financial shock.

Figure 4: Counterfactual Analysis using the Feedback Non-Standard Policy Rule, 2007q2-2010q4



NOTE: In each panel the solid line indicates the impact of the financial shock under the feedback non-standard policy rule (14), which reacts to the interbank market spread. The dashed line indicates the counterfactual in which all monetary injections are set to zero. The dark grey shaded area indicates the counterfactual results using different values for the persistence of the financial shock.

Figure 5: Impact of the Financial Shock under the Exogenous Non-Standard Policy Rule, 2007q2-2010q4



NOTE: In each panel the thick solid line indicates the impact of the financial shock under the exogenous non-standard policy rule (13). The thin dashed line indicates history. For output and consumption the thin dashed line indicates the raw data (where the trend of the series is not taken into account). The light grey shaded area indicates deviations from trend which is derived either from the HP-filter or by estimating a linear pre-crisis trend. All data is normalized to be zero in 2007q2.