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Unconventional monetary policy in an open economy

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Non-technical summary

Research Question

In empirical discussions of unconventional monetary policy, one controversial issue is the behavior of the exchange rate with no clear results. Theoretical papers addressing this topic, cannot be used as guidance either as they are usually lacking the analysis of the exchange rate. To address this gap in literature, I develop a two-country open economy model which allows me to not only look at the impact of unconventional measures on the exchange rate but also on the policy coordination of unconventional measures between central banks.

Contribution

In this paper, I implement an interbank market consisting of two banks (a savings and a lending bank) as seen in de Walque et al. (2009) into a two-country economy framework similar to Faia (2005, 2008). Moreover, I model two different unconventional measures which were commonly used during the crisis: central bank liquidity injections and asset swaps. This model setup allows for a meaningful analysis of the impact of unconventional measures on the exchange rate by capturing the transmission of unconventional measures from bank balance sheets to the economy.

Results

The results show that, different unconventional measures have different implications on the exchange rate. While liquidity injections appreciate the domestic exchange rate in the short run, they lead to a mild depreciation in the long run. Asset swaps on the contrary, cause a short run depreciation but lead to a long run appreciation of the currency. As regards the coordination of unconventional monetary policy, results show that if central banks do not coordinate liquidity injections, they lead to higher increases in GDP but also to higher fluctuations in inflation in the domestic economy, while the other economy will be negatively affected through a decline in economic growth. In contrary, when central banks coordinate asset swaps, it leads to higher GDP growth and lower fluctuations in inflation in both countries. The results of this paper suggest that the impact of unconventional measures on the exchange rate is not uniform and depends crucially on the choice of instrument. The same is true for policy coordination.

Nicht-technische Zusammenfassung

Fragestellung

Ein umstrittenes Thema in der empirischen Diskussion der unkonventionellen Geldpolitik ist das Verhalten des Wechselkurses, mit keinem klaren Ergebnis. Theoretische Arbeiten, die sich mit diesem Thema befassen, können nicht zu Rate gezogen werden, da die Analyse des Wechselkurses in diesen Arbeiten meist gänzlich fehlt. Um diese Literaturlücke zu schließen, entwickle ich ein Zwei-Länder-Modell, das mir nicht nur erlaubt die Auswirkungen der unkonventionellen Geldpolitik auf den Wechselkurs von einem theoretischen Standpunkt aus zu betrachten, sondern auch die Koordination der unkonventionellen Geldpolitik zwischen Zentralbanken.

Beitrag

In diesem Papier, implementiere ich einen Interbankenmarkt, bestehend aus zwei Banken (eine Spar- und eine Kreditbank), wie gesehen in de Walque et al. (2009), in ein Zwei-Länder-Modell ähnlich wie in Faia (2005, 2008). Außerdem modelliere ich zwei verschiedene unkonventionelle Maßnahmen, die während der Krise häufig verwendet wurden: Liquiditätsspritzen und Asset-Swaps. Dieses Modell ermöglicht eine aussagekräftige Analyse der Wirkung von unkonventioneller Geldpolitik auf den Wechselkurs, dadurch dass es die Übertragung von unkonventionellen geldpolitischen Maßnahmen von den Banken auf die Wirtschaft erfasst.

Ergebnisse

Die Ergebnisse zeigen, dass verschiedene unkonventionelle Maßnahmen unterschiedliche Auswirkungen auf den Wechselkurs haben. Während Liquiditätsspritzen, die heimische Währung kurzzeitig stärken, führen sie auf langer Sicht zu einer milden Abwertung. Im Kontrast dazu führen Asset-Swaps zu einer kurzfristigen Abwertung aber auf langer Sicht stärken sie die heimische Währung. Mit Bezug auf die Koordinierung unkonventioneller Geldpolitik zeigen die Ergebnisse, dass wenn Zentralbanken den Einsatz von Liquiditätsspritzen nicht koordinieren, diese zu einem höheren Anstieg des heimischen BIP führen, aber auch zu einer höheren Schwankung der Inflationsrate, während die andere Wirtschaft negativ beeinflusst wird durch den Rückgang des Wirtschaftswachstums. Im Gegenteil dazu stehen Asset-Swaps, wenn Zentralbanken diese koordinieren, führt dies zu höherem BIP-Wachstum und geringeren Schwankungen in der Inflationsrate in beiden Ländern. Die Ergebnisse dieser Arbeit deuten darauf hin, dass die Auswirkungen der unkonventionellen Geldpolitik auf dem Wechselkurs nicht einheitlich sind und entscheidend von der Wahl des Instruments abhängen. Das Gleiche gilt für die Koordinierung der unkonventionellen Geldpolitik.

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Unconventional Monetary Policy in an Open Economy*

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Abstract

The impact of unconventional monetary policies on exchange rates and its spillovers to other economies is not yet fully understood. In this paper I develop a two-country DSGE model with interbank markets and endogenous default probabilities to analyze the cross-border impacts of unconventional monetary policy. I examine the impact of two unconventional measures commonly used: central bank liquidity injections and asset swaps. I find that liquidity injections lead to a short run appreciation of domestic currency, but a mild long run depreciation. In contrast, asset swaps cause a short run depreciation of domestic currency, but a long run appreciation. Lastly, when both countries coordinate on the implementation of unconventional policies, the model yields the following results: Non-coordinated liquidity injections lead to higher increases with respect to output and inflation variation, but have negative spillovers on the other economy in terms of lower growth. By contrast, coordinating asset swaps leads to higher increases in output and lower fluctuation in inflation in both countries. The results of this paper suggest that coordination in unconventional monetary policy may not always yield an optimal outcome, and macroeconomic outcomes in both countries depend crucially on the choice of instrument.

JEL classification: E02; E44; E52; G21; G28
Keywords: Unconventional Monetary Policy, Quantitative Easing; Asset Swaps; Open Economy DSGE; Currency Wars; Policy Coordination
Interbank Model; Nominal Rigidities

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1 Introduction

The severe negative impact of the 2007-09 financial crisis on the global economy has brought monetary authorities to the limits of their policies. Central banks all over the world had to apply unprecedented measures after their conventional tools, such as decreasing the interest rate, became ineffective when reaching the zero lower bound. In this process, central banks used very different approaches. For instance, in December 2008 the Federal Reserve (Fed) intervened aggressively into financial markets, within its framework of its quantitative easing program (QE1), by purchasing up to USD 1350 billion (9.4% of GDP) in mortgage-backed securities. The ECB and other central banks responded to the default of Lehman Brothers by providing EUR70 billion (0.7% of Euro zone GDP) to the interbank market, while Bank of Japan provided JPY 5 billion (0.001% of GDP) and Bank of England GBP 20 billion (1.4% of GDP). The use of unconventional measures continued even after the financial crisis. In September 2012 the ECB announced outright purchases of government bonds to address a “malfunction in the monetary transmission mechanism”. Shortly after ECB’s announcement, the Fed confirmed a third round of quantitative easing (QE3) to support stronger economic recovery. Japan turned to aggressive quantitative easing measures paired with increased government spending which are also known as “Abenomics” named after Shinzo Abe, the current Prime Minister, who took over office in December 2012.

While these unconventional measures are generally viewed as helpful to the economy where they are applied, some foreign country representatives strongly criticize their use. For example, in October 2010 China’s trade minister, Chen Deming, argued that the Fed’s second round of quantitative easing would depreciate the value of the US Dollar causing an imported inflationary shock for China. The finance minister of Brazil, Guido Mantega, associated the situation to an “international currency war”. This critical perception of unconventional measures contrast with the joint cooperation of several central banks in November 2011, where the European Central Bank, the Federal Reserve, the Bank of Canada, the Bank of England, the Bank of Japan, and the Swiss National Bank coordinately supplied liquidity to global financial markets to ease frictions on credit supply. These divergent views on the effect of unconventional monetary policy (UMP) lead to several questions. Do unconventional measures actually lead to a depreciation of the exchange rate? And if so, which of the various measures cause a devaluation of domestic currency? Does central bank coordination in unconventional monetary policy amplify spillovers or do they cancel each other out?

Concerning the empirical strand of literature, there are several papers which examine the impact of unconventional measures on the exchange rate. However, these studies partly contradict each other. For instance, Kuttner and Posen (2001) use a VAR analysis to assess the impact of liquidity injections in Japan. According to their paper, a liquidity shock depreciates the yen, but the depreciation is not statistically significant. They also find that quantitative easing initially increases prices, but the effect is reversed after a few quarters. Honda et al. (2007) show that quantitative easing increases output but has no significant effect on the price level because quantitative easing transmits through stock prices and not through general prices. A recent study by Fratzscher, Lo Duca and Straub (2012) analyzes the effect of announcements and actual operations of the Federal Reserve’s unconventional monetary policy measures on portfolio allocations across asset classes as well as on asset prices in 65 countries. Fratzscher et al. (2012) find that QE1 and QE2 announcements as well as treasury purchases all weakened the US dollar but that liquidity injections induced a US dollar appreciation. According to Fratzscher et al. (2012) QE1 and QE2 announcements, and treasury purchases triggered net outflows from US assets, thus depreciating the US dollar, whereas liquidity injections aimed at repairing dysfunctional markets attracted capital into US markets and thus strengthened the US dollar.

Regarding the theoretical strand of literature, there is an increasing number of papers assessing the impact of unconventional measures in a DSGE setup (e.g. Gertler and Karadi (2009), Gertler and Kiyotaki (2010), Dib (2010), Gieck and Trazyck (2010)) but it is done using a closed economy model. Consequently, these papers cannot contribute to the questions stated above. To the best of my knowledge, there is only one paper by Dedola, Karadi, and Lombardo (2012, henceforth DKL) which examines effects of unconventional measures in an open economy framework. However, DKL concentrate on the assessment of cooperation and non-cooperation in unconventional policies in a *real* economy model, therefore they are not able to address the behavior of the exchange rate or inflation. The authors find that when economies are hit by a *capital quality shock*, unconventional policies are generally welfare decreasing, i.e. both under cooperation and non-cooperation. When they look at a *financial shock*, they find that central banks should aggressively offset the impact of the shock by coordinating policies.

With this paper I am aiming at closing the gap in DSGE literature and analyze the behavior of the exchange rate after the introduction of unconventional measures. Furthermore, I contribute to the literature on coordination of monetary policy by looking at spillovers arising from simultaneous (coordination) and non-simultaneous (non-coordination) implementations of unconventional measures. I interpret the simultaneous implementation of UMP in both countries as coordination in monetary policy whereas the sole implementation of UMP in only one country is regarded as non-coordination in monetary policy. In order to address the question of exchange rate behavior, I develop a two country DSGE model similar to Faia (2005, 2008) but with a complete international market[1]. The financial crisis proofed that banks are important in the transmission of monetary policy and since most unconventional measures where aimed at banks, my model includes a meaningful interbank market with both financial and nominal frictions. Financial frictions are introduced through endogenous default of banks and firms like in de Walque et al. (2009) and nominal frictions are introduced through price adjustment cost *à* la Rotemberg like in Gieck and Trazyck (2010). The most common unconventional measures used during the financial crisis are replicated in this paper, liquidity injections and asset swaps. Liquidity injections are associated with the creation of new money and expand the balance sheet of banks. Whereas asset swaps of impaired loans in exchange for risk free assets affect the composition of banks' assets and the quality of banks's balance sheets without changing balance sheet totals. The interbank market consists of two banks per country, a deposit bank and a lending bank. Both banks face endogenous balance sheet decisions and are constrained by capital regulation rules. The deposit bank collects savings from domestic households and provides loans to domestic lending banks. Lending banks supply loans to domestic capital producing firms and lend on the interbank market. Deposit banks are net creditors whereas lending banks are net debtors in the interbank market. Both lending banks and capital producing firms can default on their loans, but are subject to quadratic adjustment costs if they do so. These defaults have the effect of financial accelerators. In particular, the default of the capital producing firm leads to a default of the lending bank which in turn leads

[1]The assumptions of a complete international market facilitates the analysis of spillovers under coordination.

to a decrease in credit supply on the interbank market by the deposit bank, thereby amplifying the crisis. The interbank market is based on the model by de Walque et al. (2009) and allows me to take into account the heterogeneity of the banking sector[2]. Unconventional measures are implemented according to Dib (2010), namely through exogenous shocks to the banking sector. However, there is no international interbank market, meaning that domestic banks do not borrow or lend to foreign banks.

In this paper, I examine two scenarios for each unconventional measure either only one central bank or both central banks introduce unconventional policies which I interpret as coordination and non-coordination in monetary policy. I find that if only one central bank injects liquidity into the interbank market, the exchange rate appreciates for 2 periods and depreciates thereafter. The appreciation in the first 2 periods is caused by the increase in credit supply which also hikes up prices and thus the exchange rate (which is defined by the terms of trade). As soon as credit supply starts to fall in the third period (although it is still above its steady state) prices also decline leading to a depreciation of the exchange rate. By contrast, asset swaps lead to a slight depreciation of the exchange rate in the first period and appreciate it thereafter. Asset swaps lead to a decrease in credit growth in the first period which also depresses prices, thus depreciating the exchange rate. After the first period, however, assets swaps increase credit supply together with prices leading to an appreciation in the long run. Another result of this paper is that coordinating unconventional policies is advisable in some cases but not in others, it mainly depends on the target of the central bank and the instrument it wishes to use. For instance, in the case of liquidity injections, the best outcome in terms of higher GDP is achieved with non-coordination. Then, however, the other country will be affected by negative spillovers which lead to declines in GDP. With regard to inflation, liquidity injections have the disadvantage that they increase inflation variation by the same amount under coordination and non-coordination. By contrast, asset swaps increase output and lower inflation variation the most only if coordinated. But even in the case of non-coordination, the spillovers coming from asset swaps are generally positive. While both measures are able to increase GDP, the impact of liquidity injections is substantially stronger than the impact of asset swaps. This is due to way both measures are modeled: liquidity injections create additional resources which banks can use to increase credit supply; asset swaps just change the quality of banks assets not the amount of assets. Thus the impact of asset swaps is less pronounced. For the same reason is variation in inflation substantially higher under liquidity injections than under assets swaps.

In a second step, I analyze if both measures are able to mitigate negative effects from a financial market shock. This financial shock is supposed to mitigate the beginning of the financial crisis where fire sales in mortgage-backed-securities lead to substantial losses in the market book of banks causing the default of financial institutions and triggering the financial crisis. In this model, the financial market shock leads to a substantial loss in the market book of banks thereby decreasing their profits and increasing their default rate. This in turn leads to lower credit supply on the interbank market and thus to a credit crunch. When it comes to the ability of mitigating negative effects from a financial shock, results show that liquidity injection perform better than asset swaps. The impact of liquidity injections, for instance, is more pronounced than of asset

[2]For more information on the implications of the heterogeneity and the relationship between deposit banks and lending banks as well as the implications of the endogenous defaults, I recommend to read the original paper by de Walque et al. (2009).

swaps, where it is sufficient to inject liquidity as high as 5% of GDP to mitigate negative effects, asset swaps need to be substantially higher in order to achieve the same impact. If both countries experience a financial market shock the lowest decline in GDP after the shock is attained if a central bank does not coordinate liquidity injections. This, however, has negative spillovers on the other economy which will see even stronger declines in GDP due to the current account deficits caused by the depreciating exchange rate. On top of that, the application of liquidity injections will increase variation in inflation. In the case of assets swaps the opposite is true, the lowest decline in GDP and lowest fluctuation in inflation after a financial shock is achieved if countries coordinate asset swaps. If assets swaps are coordinated the initial decline in GDP is not as steep as in the non-coordinated case and negative trade balances on either side are avoided. The results from the financial shock experiment are in line with the general finding stated above, that non-coordinated liquidity injections lead to higher GDP growth but have negative spillovers on the other economy, whereas assets swaps have a stronger impact under coordination.

The remainder of this paper is organized as follows. The setup of the two-country model is introduced in section 2.2. The calibration of the model is documented in section 2.3. Section 2.4, shows and evaluates the results from the impulse response analysis and section 2.5 concludes.

2 The Open Economy Model

The model consists of two countries, home and foreign. Each country has a representative household, an interbank market, a production sector, and a central bank. The interbank market consist of two banks, a deposit bank and a lending bank. The deposit bank collects household's savings and supplies loans to the lending bank. The lending bank relies on loans from deposit banks on which it can default and provides loans to capital producing firms. The production sector consists of capital goods, intermediate goods, and final goods producers. Capital producers obtain loans from lending banks on which they can default and rent capital to the intermediate goods producing firms. These firms use labor and capital to produce intermediate goods and face price adjustment costs *à*-la Rotemberg (1982). Domestic and foreign intermediate goods are then processed into final goods by the final good producers. The central bank sets interest rates according to a Taylor-type policy rule and carries out unconventional measures. Since the model lacks any distinct fiscal or supervisory authorities, I assume that the central bank takes over these roles as well. In particular, it supervises the banking sector through capital ratios. All agents are infinitely lived. Both countries have the same technologies, preferences and operate in a complete international market. An asterisk denotes foreign variables.

2.1 Households

Household's maximization program is given by:

$$\max_{C_t,N_t,D_t^h,B_t^*} \sum_{s=0}^{\infty} \beta^s E_t \left\{ log(C_{t+s}) + \bar{m} log(1-N_{t+s}) - \frac{\chi}{2} \left(\frac{D_t^h}{1+r_{t+s}} - \frac{\bar{D}^h}{1+\bar{r}} \right)^2 \right\} \tag{1}$$

Households consume an aggregate in final goods C_t, and decide upon leisure time $(1-N_t)$ where $\bar{m}$ is households leisure utility parameter. They also have the possibility to invest in state-contingent assets, B_t^* and in domestic deposits D_t^h. The state-contingent asset offers a discount rate r_t^* whereas deposits offer a rate r_t. For technical reasons I impose a target in deposits $\bar{D}^h$ via a quadratic disutility term together with a target interest rate for deposits $\bar{r}$. This is necessary in order to determine D^h. It can be interpreted as a long-run optimal target in deposits from which the households do not like to deviate.

Households face following budget constraint:

$$C_t + \frac{D_t^h}{1+r_t} + \frac{e_t^r B_t^*}{1+r_t^*} = w_t N_t + \frac{D_{t-1}^h}{\pi_t} + \frac{e_t^r B_{t-1}^*}{\pi_t} + (1-v_{db})\,\Pi_t^{db} + (1-v_{lb})\,\Pi_t^{lb} \tag{2}$$

where $e_t^r = \frac{e_t P_t^*}{P_t}$ is the real exchange rate and $\pi_t = P_t/P_{t-1}$ is domestic CPI-inflation. Households receive a share of banks profits in line with retained earnings ratios v_d and v_l.

When households maximize (1) with respect to (2) the following first-order conditions apply:

$$w_t = \frac{C_t}{1-N_t}\bar{m} \tag{3}$$

$$\frac{1}{C_t} = \beta E_t\left(\frac{(1+r_t)}{C_{t+1}\pi_{t+1}}\right) - \chi\left(\frac{D_t^h}{1+r_t} - \frac{\bar{D}^h}{1+\bar{r}}\right) \tag{4}$$

$$\frac{\lambda_t}{1+r_t^*} = E_t\left(\frac{e_{t+1}^r}{e_t^r}\frac{\lambda_{t+1}}{\pi_{t+1}}\right) \tag{5}$$

Equation (3) states the optimal labor supply conditions. Equation (4) is the Euler equation with respect to deposits. Equation (5) is the Euler equation with respect to international state contingent bonds, where λ denotes the Lagrange multiplier on the constraint (2).

The behavior of foreign households is symmetric and leads to the following risk sharing condition:

$$\lambda_t = \frac{\lambda_t^*}{e_t^r} \tag{6}$$

Equation (6) means that domestic marginal utility of consumption is proportional to its foreign counterpart[3].

2.2 Banks

2.2.1 Deposit Banks

Deposit banks allocate their resources between deposits from households D_t^{db}, loans to the interbank market I_t^{db}, own funds F_t^{db}, and an exogenous market book $\bar{B}^{db}$ in order to maximize the sum of all expected payoffs. The payoffs comprise a concave function of profits Π_t^{db} and a utility from own funds. The concave profit function and the assumption of a positive utility d_{db} for own funds F_{t+s}^{db} above the minimum capital requirement is taken from Goodhart et al. (2005). This fixes the minimum capital requirement ratio $k = 0.08$, $\widehat{w} = 0.2$ and $\bar{w} = 1.2$ which are the respective weights on interbank loans and on the market book[4]. Deposit banks are symmetric across countries, thus foreign deposit banks face the same maximization problem.

[3] As shown in Schmitt-Grohe and Uribe (2001).

[4] The buffer above the minimum capital requirement rules out a corner solution and can also be found in the data.

The maximization program is:

$$\max_{D_t^{db}, I_t^{db}, F_t^{db}} \sum_{s=0}^{\infty} E_t \bar{\beta}^s \left\{ \log\left(\Pi_{t+s}^{db}\right) + d_{db}\left[F_{t+s}^{db} - k\left(\widehat{w} I_{t+s}^{db} + \bar{w}\bar{B}^{db}\right)\right]\right\} \tag{7}$$

under the following constraints:

$$F_t^{db} = (1-\xi_{db})\frac{F_{t-1}^{db}}{\pi_t} + \upsilon_{db}\Pi_t^{db} \tag{8}$$

$$\Pi_t^{db} = \left\{\frac{\delta_t I_{t-1}^{db}}{\pi_t} - \frac{I_t^{db}}{1+r_t^i} + \frac{D_t^{db}}{1+r_t^l} - \frac{D_{t-1}^{db}}{\pi_t} + \zeta_{db}(1-\delta_{t-1})\frac{I_{t-2}^{db}}{\pi_t} + \frac{\bar{\rho}\bar{B}^{db}}{\pi_t}\right\} \tag{9}$$

Equation (8) shows the dynamics for own funds F_t^{db}. Own funds are increased each period by a share υ_{db} of profits. Moreover, a small fraction ξ_{db} of own funds is put into an insurance scheme run by a public agent. This is due to the fact that deposit banks face losses on their interbank loans. Equation (9) denotes the evolution of profits, where ζ_{db} is the share which banks can recover from defaulted interbank loans due to the insurance fund they pay in. The return on the market book $\bar{B}$ is $\bar{\rho}$, and r_t is the interest rate set by the central bank. In contrast to lending banks it is assumed that deposit banks never default.

The first order conditions of the above maximization program are the following:

$$\frac{\lambda_t^{db}}{1+r_t} = \bar{\beta}E_t\left\{\frac{\lambda_{t+1}^{db}}{\pi_{t+1}}\right\} \tag{10}$$

$$\frac{\lambda_t^{db}}{1+r_t^i} = \bar{\beta}E_t\left\{\frac{\delta_{t+1}\lambda_{t+1}^{db}}{\pi_{t+1}} + \bar{\beta}^2\zeta_{db}\left(1-\delta_{t+1}\right)\frac{\lambda_{t+2}^{db}}{\pi_{t+1}}\right\} - d_{db}k\widehat{w} \tag{11}$$

$$\frac{1}{\Pi_t^{db}} = \lambda_t^{db} + \left(\frac{1}{\Pi_{t+1}^{db}\pi_{t+1}} - \lambda_{t+1}^{db}\right)\bar{\beta}(1-\xi_{db}) - d_{db}\upsilon_{db} \tag{12}$$

where λ_t^{db} denotes the Lagrange multiplier on the profit function (9). Equations (10) and (11) are the Euler conditions for households deposits and loans to lending banks, respectively. Equation (12) states the optimal choice for holdings of own fund.

2.2.2 Lending banks

Lending banks provide loans to the capital producing firms L_t^{lb}, borrow from the interbank market I_t^{lb}, invest in an exogenous market book $\bar{B}^{lb}$ with a yield of $\bar{\rho}$, choose their holdings in own funds F_t^{lb}, and their optimal repayment rate δ_t to maximize the expected sum of all future payoff. The payoffs comprise a concave function of profits Π_t^{db} and a utility d_{lb} from funds own above the implied minimum capital. This fixes the minimum capital ratio k and $\widetilde{w}$ and $\bar{w}$, the respective weights on loans and on the market book. In contrast to deposit banks, lending banks can default (1-δ_t). However, if lending banks default they face quadratic search costs $-\frac{\varphi}{2}\left[(1-\delta_{t-1})(\frac{I_{t-2}^{lb}}{\pi_{t-1}} + d_\delta)\right]^2$, where d_δ stands for a fixed cost of default[5] which is independent from the total defaulted amount

[5]The expenses related to default consist of a variable part that relates to the notional of outstanding loans in the economy and an additional fixed cost. Linearity of cost would imply indeterminacy for Equation (17). de Walque et al. (2009) solve this technicality by splitting the expenses related to default into non-pecuniary costs that affect utility and pecuniary costs that impact profits. However, as they acknowledge, this "double cost" lacks pure micro foundations.

$(1-\delta_{t-1})\frac{I_{t-2}^{lb}}{\pi_{t-1}}$. The quadratic formulation prevents indeterminacy in the first order condition. .

Lending banks solve the following maximization problem:

$$\max_{L_t^{lb}, I_t^{lb}, F_t^{lb}, \delta_t} \sum_{s=0}^{\infty} E_t \bar{\beta}^s \left\{ \log\left(\Pi_{t+s}^{lb}\right) + d_{lb}\left[F_{t+s}^{lb} - k\left(\widetilde{w}L_{t+s}^{lb} + \bar{w}\bar{B}^{lb}\right)\right]\right\} \tag{13}$$

where Π_t^{lb} are profits, under the constraints:

$$F_t^{lb} = (1-\xi_{lb})\frac{F_{t-1}^{lb}}{\pi_t} + v_{lb}\Pi_t^{lb} \tag{14}$$

$$\Pi_t^{lb} = \left\{ \frac{\alpha_t L_{t-1}^{lb}}{\pi_t} - \frac{L_t^{lb}}{1+r_t^b} + \frac{I_t^{lb}}{1+r_t^i} - \frac{\delta_t I_{t-1}^{lb}}{\pi_t} - \frac{\varphi}{2}\left[(1-\delta_{t-1})\left(\frac{I_{t-2}^{lb}}{\pi_{t-1}} + d_\delta\right)\right]^2 \right.$$
$$\left. + \zeta_{lb}(1-\alpha_{t-1})\frac{L_{t-2}^{lb}}{\pi_{t-1}} + \frac{\bar{\rho}\bar{B}^{lb}}{\pi_t} \right\} \tag{15}$$

Equation (14) displays the dynamics for own funds of lending banks. Like deposit banks, lending banks increase their own funds each period by a share v_{lb} of profits and pay a fraction ξ_{lb} into an insurance fund. The evolution of lending bank's profits is given in equation (15) where ζ_{lb} is the share lending banks can recover from defaulted loans due to the insurance fund, $\bar{\rho}$ is the return on the market book $\bar{B}^{lb}$, and r_t^i is the interbank market rate.

The first order conditions of the above maximization program are the following:

$$\frac{\lambda_t^{lb}}{1+r_t^b} = \bar{\beta}E_t\left\{\frac{\lambda_{t+1}^{lb}\alpha_{t+1}}{\pi_{t+1}} + \bar{\beta}^2\lambda_{t+2}^{lb}\zeta_{lb}(1-\alpha_{t+1})\frac{1}{\pi_{t+1}}\right\} - d_{lb}k\widetilde{w} \tag{16}$$

$$\frac{\lambda_t^{lb}}{1+r_t^i} = \bar{\beta}E_t\left\{\frac{\lambda_{t+1}^{lb}\delta_{t+1}}{\pi_{t+1}} + \bar{\beta}^2\lambda_{t+2}^{lb}\varphi(1-\delta_{t+1})^2\left(\frac{I_t^{lb}}{\pi_{t+1}^2} + d_\delta\right)\right\} \tag{17}$$

$$\lambda_t^{lb}\frac{I_{t-1}^{lb}}{\pi_{t+1}} = E_t\left\{\bar{\beta}\lambda_{t+1}^{lb}\varphi(1-\delta_t)\left(\frac{I_{t-1}^{lb}}{\pi_t} + d_\delta\right)^2\right\} \tag{18}$$

$$\frac{1}{\Pi_t^{lb}} = \lambda_t^{lb} + \left(\frac{1}{\Pi_{t+1}^{lb}\pi_{t+1}} - \lambda_{t+1}^{lb}\right)\bar{\beta}(1-\xi) - d_{lb}v_{lb} \tag{19}$$

where λ_t^{lb} denotes the Lagrange multiplier on the profit function (15). Equation (16) and (17) are the Euler conditions for providing loans to capital producing firms and borrowing from deposit banks, respectively. Equation (18) shows the trade-off between redeeming an interbank loan today and tomorrow which is associated with a variable and a fixed cost. Equation (19) displays the optimal choice for own fund holdings.

2.3 Non-financial Firms

2.3.1 Capital Goods Producers

Capital producers maximize profits Π_t^c by selling out their capital K_t to intermediate goods producers against a price z_t. In order to invest in new capital, they acquire loans L_t from lending banks on which they can default (the time varying default rate is (1-α_t)). When capital producers default they face quadratic search cost $-\frac{\Psi}{2}\left((1-\alpha_{t-1})\left(\frac{L_{t-2}}{\pi_{t-1}}+d_c\right)\right)^2$, where I distinguish between variable cost $(1-\alpha_{t-1})\frac{L_{t-2}}{\pi_{t-1}}$ and fixed cost $(1-\alpha_{t-1})\,d_c$ of default[6]

Capital producers solve the following optimization program:

$$\max_{K_t,L_t,\alpha_t}\sum_{s=0}^{\infty}E_t\bar{\beta}^s\left\{\Pi^c_{t+s}\right\} \tag{20}$$

Profits are defined as:

$$\Pi^c_t = z_tK_t - \frac{\alpha_tL_{t-1}}{\pi_t} - \frac{\Psi}{2}\left((1-\alpha_{t-1})\left(\frac{L_{t-2}}{\pi_{t-1}}+d_c\right)\right)^2 \tag{21}$$

subject to the following constraint:

$$K_t = (1-\tau)\,K_{t-1} + \frac{L_t}{1+r^b_t} \tag{22}$$

where τ it the capital depreciation rate and r^b_t is the interest rate for loans.

Following first order conditions emerge:

$$\frac{\lambda^c_t}{1+r^b_t} = \bar{\beta}E_t\left[\frac{\alpha_{t+1}}{\pi_{t+1}} + \bar{\beta}\Psi\left(\frac{(1-\alpha_{t+1})^2}{\pi_{t+1}}\left(\frac{L_t}{\pi_{t+1}}+d_c\right)\right)\right] \tag{23}$$

$$\frac{L_{t-1}}{\pi_t} = \bar{\beta}\Psi\,(1-\alpha_t)\left(\frac{L_{t-1}}{\pi_t}+d_c\right)^2 \tag{24}$$

$$z_t = \lambda^c_t - \bar{\beta}E_t\left[\lambda^c_{t+1}(1-\tau)\right] \tag{25}$$

where λ^c_t denotes the Lagrange multiplier on the constraint (22). Equation (23) equalizes today's discounted shadow value of capital to its discounted cost in period $t+1$ plus the remaining cost in period $t+2$. Equation (24) defines that the discounted marginal cost of paying back the loan today is equal to the marginal discounted quadratic search cost of tomorrow in addition to a fixed default cost parameter. Equation (25) states that the price for capital is equal to the differential between today's and tomorrow's shadow value.

2.3.2 Intermediate Goods Producers

The intermediate goods production sector consists of a continuum of monopolistically competitive firms each maximizing profits $\Pi^f_{t+s}(i)$ by choosing an optimal amount of labor $N(i)_t$ which is supplied by households, and an optimal amount of capital $K(i)_t$ which is supplied by capital producers. Intermediate goods producers also set the price level where they have to take into account price adjustment costs á la Rotemberg. They solve the following optimization program:

$$\max_{P_{H,t}(i),N_t(i)K_t(i)}\sum_{s=0}^{\infty}E_t\bar{\beta}^s\left\{\Pi^f_{t+s}(i)\right\} \tag{26}$$

where the profit function is given by:

[6] By this I avoid modeling a default parameter in the utility function of capital goods producers like in de Walque et al. (2009), see also footnote 3 .

$$\Pi_t^f(i) = \frac{P_{H,t}(i)}{P_{H,t}} X_t(i) - w_t N_t(i) - z_t K_t(i) - \frac{\upsilon}{2}\left(\frac{P_{H,t}(i)}{P_{H,t-1}(i)} - \overline{\pi}\right)^2 X_t \tag{27}$$

υ is firms price change cost or the degree of price stickiness.

Each intermediate goods producer is facing a downward-sloping demand curve for its differentiated product i:

$$X_t(i) = K_t^{\mu}(i) \left(\exp\left(A_t(i)\right) N_t(i)\right)^{1-\mu} \geq \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\theta} X_t \tag{28}$$

where $X_t(i) = K_t^{\mu}(i) \left(\exp\left(A_t\right) N_t(i)\right)^{1-\mu}$ is a constant return to scale production function with $A_t = \rho_a A_{t-1} + \varepsilon_t^A$ functioning as an aggregate productivity shock. $X_t = (X_{H,t} + X_{H,t}^*)$ is world demand for the domestic intermediate good and θ is the elasticity of substitution between two intermediate goods. Since firms are symmetric, they will all set the same price s.t. $P_t(i) = P_t$. Let mc_t be the Lagrange multiplier associated with equation (28). I obtain following first order conditions when solving the above optimization problem:

$$w_t = mc_t(1-\mu)\left(\frac{K_t}{N_t}\right)^{\mu} \left(\exp\left(A_t\right)\right)^{1-\mu} \tag{29}$$

$$z_t = mc_t \mu \left(\frac{K_t}{N_t}\right)^{\mu-1} \left(\exp\left(A_t\right)\right)^{1-\mu} \tag{30}$$

$$\upsilon\left(\pi_{H,t} - \overline{\pi}\right)\pi_{H,t} X_t = (1-\theta+\theta mc_t) X_t + \beta \bar{E}_t\left[\upsilon\left(\pi_{H,t+1} - \overline{\pi}\right)\pi_{H,t+1} X_{t+1}\right] \tag{31}$$

where $\pi_{H,t} \equiv \frac{P_{H,t}}{P_{H,t-1}}$ is the gross inflation. Equations (29) and (30) are the familiar marginal cost equations where wages are equal to marginal cost of labor and the rental rate of capital to the marginal cost of capital. Equation (31) is the Phillips-Curve stating that today's domestic inflation is dependent on world demand for the domestic intermediate good and expectations on future domestic inflation.

2.3.3 Final Good Production

The final good Y_t is obtained by combining domestic $X_{H,t}$ and imported $X_{F,t}$ intermediate goods according to the following CES function:

$$Y_t \equiv [\gamma^{\frac{1}{\eta}} X_{H,t}^{\frac{\eta-1}{\eta}} + (1-\gamma)^{\frac{1}{\eta}} X_{F,t}^{\frac{\eta-1}{\eta}}]^{\frac{\eta}{\eta-1}} \tag{32}$$

where $X_{H,t} \equiv \left(\int_0^1 X_{H,t}(i)^{\frac{\theta-1}{\theta}} di\right)^{\frac{\theta}{\theta-1}}$ is an aggregate of domestic intermediate goods and $X_{F,t} \equiv \left(\int_0^1 X_{F,t}(i)^{\frac{\theta-1}{\theta}} di\right)^{\frac{\theta}{\theta-1}}$ is an aggregate of imported intermediate goods. When I solve following profit maximization problem:

$$\max_{\{X_{H,t}(i), X_{F,t}(i)\}_{t=0}^{\infty}} P_t Y_t - \int_0^1 P_{H,t}(i) X_{H,t}(i) di - \int_0^1 P_{F,t}(i) X_{F,t}(i) \tag{33}$$

I receive the optimal demands for each type of the final good:

$$X_{H,t}(i) = \gamma \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\eta} X_{H,t}; \quad X_{F,t}(i) = (1-\gamma)\left(\frac{P_{F,t}(i)}{P_{F,t}}\right)^{-\eta} X_{F,t} \tag{34}$$

$$X_{H,t} = \gamma \left(\frac{P_{H,t}}{P_t}\right)^{-\eta} Y_t; \quad X_{F,t} = (1-\gamma)\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} Y_t \tag{35}$$

where $P_{H,t} \equiv \left(\int_0^1 P_{H,t}(i)di\right)^{\frac{\theta}{\theta-1}}$, $P_{F,t} \equiv \left(\int_0^1 P_{F,t}(i)di\right)^{\frac{\theta}{\theta-1}}$, $P_t \equiv [\gamma P_{H,t}^{1-\eta} + (1-\gamma)P_{F,t}^{1-\eta}]^{\frac{1}{1-\eta}}$ are the respective price indices.

2.3.4 Equilibrium Conditions

Equilibrium in the asset market implies that the world net supply of bonds is zero. After imposing market clearing for each intermediate good i, aggregating and substituting the relevant demand functions in (34), market clearing in the intermediate sector implies:

$$X_t = \gamma \left(\frac{P_{H,t}}{P_t}\right)^{-\eta} Y_t + (1-\gamma)\left(\frac{P_{F,t}}{P_t}\right)^{-\eta} Y_t + \frac{\upsilon}{2}\left(\pi_{H,t} - \overline{\pi}\right)^2 Y_t \tag{36}$$

Market clearing in the final goods sector is given by:

$$Y_t = C_t + \frac{L_t^c}{1+r_t^b} \tag{37}$$

where $\frac{L_t^c}{1+r_t^b}$ is the amount of loans entrepreneurs invest in new capital.

Finally, it is assumed that the deposit, interbank, and commercial loan markets clear in the long run:

$$D_t^{db} = D_t^h \tag{38}$$

$$I_t^{lb} = I_t^{db} \tag{39}$$

$$L_t^c = L_t^{lb} \tag{40}$$

2.4 Central Bank and Unconventional Measures

In normal times the central bank conducts its policy according to a Taylor-type policy rule:

$$(1+r_t) = (1+\bar{r})^{(1-\mu_r)}\left(1+r_{t-1}\right)^{\mu_r}\left(\frac{\pi_t}{\overline{\pi}}\right)^{Q_\pi} \tag{41}$$

At times of financial distress it uses unconventional instruments: liquidity injections M_t or asset swaps S_t to support the lending bank

Then the budget constraint of domestic lending banks (15) changes to[7]:

$$\Pi_t^{lb} = \Bigg\{ \frac{\alpha_t L_{t-1}^{lb}}{\pi_t} - \frac{L_t^{lb}}{1+r_t^b} + \frac{I_t^{lb}}{1+r_t^i} - \frac{I_{t-1}^{lb}}{\pi_t}$$
$$-\frac{\varphi}{2}\left[(1-\delta_{t-1})\left(\frac{I_{t-2}^{lb}}{\pi_{t-1}} + d_\delta\right)\right]^2 + \zeta_{lb}(1-\alpha_{t-1})\frac{L_{t-2}^{lb}}{\pi_{t-1}} + \frac{\bar{\rho}\bar{B}^{lb}}{\pi_t} + (\frac{1}{1+r} - \frac{1}{1+r_t^b})S_t + \frac{M_t}{1+r_t} - \frac{M_{t-1}}{\pi_t} \Bigg\} \tag{42}$$

I assume that asset swaps S_t are executed within one period. In other words, lending banks swap a fraction of loans and at the same time receive the equivalent amount in central bank bonds. Liquidity injections M_t, however, are paid back one period later and become effective in the equilibrium condition for the loan market, such as the following holds in the short run:

$$L_t^c = M_t + L_t^{lb} \tag{43}$$

The unconventional monetary tools are modeled as $AR(1)$ processes:

$$M_t = \rho_M M_{t-1} + \varepsilon_t^M \tag{44}$$

$$S_t = \rho_S S_{t-1} + \varepsilon_t^S . \tag{45}$$

3 Calibration

The two countries are assumed to be symmetric in every way. Table 1 in the Appendix shows the calibrated parameters.

Households.

The elasticity of substitution between foreign and domestic goods η is equal to 1.5 as in Backus et al. (1992). The export over GDP ratio $1-\gamma$ is set to 0.2 which is compatible with Kollmann (2004). Households leisure utility parameter $\bar{m}$ is deduced from the model and is equal to 3.14.

Production Sector.

Employment is normalized to $N = 0.2$ which means that employers work 20% of total available hours [8]. The capital share in the Cobb-Douglas production function is set to $\mu = 0.3$ which is in accordance with the capital share of 30% observed in the euro area and the US. It is assumed that capital stock is 10 times higher than production. Capital depreciation rate is set to $\delta = 0.03$. This implies an investment ratio to output of $0.3 = \delta\frac{K}{Y}$. Although, in the standard RBC literature capital stock is usually 8 times higher than production, this is needed to avoid negative search cost γ on the defaulted amount. The autoregression coefficient in the technology equation ρ_a is equal 0.95 which is standard in the RBC literature. Following Faia (2007) the price elasticity of demand θ is set to 6 and the price adjustment cost parameter υ is set to 17.5. The value for the default rate of capital producing firms is equal to 5% (and therefore $\alpha_t = 0.95$ in steady state)

[7]Due to symmetry, the same holds for the foreign lending bank.

[8]This is in line with real data, where $0.2 = (40 * 44)/(52 * 7 * 24)$

which is inferred from the US courts and the Bureau of Labor Statistics quarterly pre-crisis data on business bankruptcies. The data are based on the number of non-financial corporations that go bankrupt. This enables me to derive $\Psi = 103.04$ the variable default cost parameter of capital producing firms and $d_c = 0.001$ the fixed default cost parameter.

Banking Sector.

I set the deposit rate to $r = 0.35\%$, so the annual deposit rate is equal to 1.4%. The market book offers a mere of $\rho = 1\%$, which is consistent with the average quarterly return of the Dow Jones Industrial Average Index from 1980Q1 to 2012Q2. Lending banks default rate is set to $\delta = 0.98$ which is derived from the pre-crisis data provided by the Federal Deposit Insurance Corporation. These data encompasses the number of bank failures. When calibrating the model I impose D^h/L^{lb} to be around 2 and $I^{db}/L^{lb} = I^{lb}/L^c$ around 0.5, which is in line with pre-crisis statistics of the Federal Reserve System. The market book for each bank equals to the amount of loans to capital producers: $\bar{B}^{db} = \bar{B}^{lb} = L^{lb}$. The weights of bank assets are aligned to the solvability regulation of the Basel agreement. Loans to banks with a rating of AAA to $AA-$ (S&P) have to be weighted with 20%, thus $\widehat{w} = 0.2$. A loan to an enterprise with a rating of A+ to A- (S&P) has to be weighted with 50% thus $\widetilde{w} = 0.5$. The capital ratio is set to $k = 8\%$. Banks are supposed to allocate half of their profits to own funds ($v_b = v_l = 0.5$) and the remaining 50% are consumed immediately. Through the insurance scheme I assume that banks can recover 80% of their bad loans; in exchange, banks must pay a premia of 6% and 7% of their funds ($\xi_{db} = 0.06$ for deposit banks and $\xi_{lb} = 0.07$ for lending banks, rates differ due to differences in default rates for firms and lending banks) in order to benefit from this provision. The fixed default cost parameter for the lending bank d_δ is equal to 0.05. Other parameters - default cost parameter ω and own funds utility parameters for both bank types, d_{F^b} , d_{F^l} , b_{F^b}, and b_{F^l} - are inferred from the restrictions mentioned above.

Central Bank.

The Taylor-type monetary policy rule contains parameters that are set according to specifications used in the literature and satisfy the Taylor rule principle ($\mu_r = 0.8$, $Q_\pi = 1.7$. Regression parameters for all unconventional monetary tools $\rho_{(\cdot)}$ are set to 0.85.

4 Quantitative Results

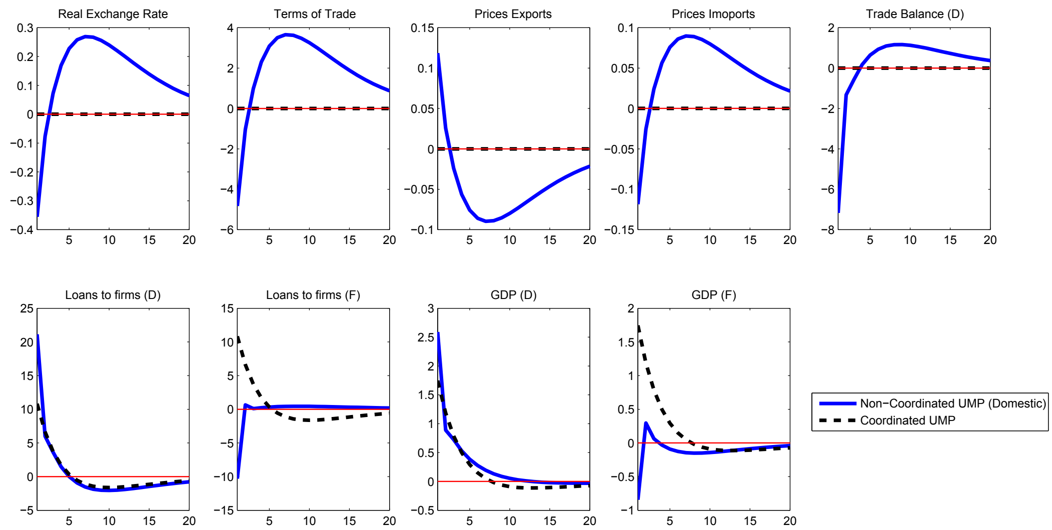
4.1 Impulse Responses

4.1.1 Liquidity injections

Figure 1 shows a liquidity injection shock to lending banks which is equal to 5% of GDP. The solid line represents responses when only the domestic central bank applies this unconventional measure and the dashed line represents responses when both the domestic and foreign central bank provide liquidity to lending banks at the same time. In accordance with the AR(1) processes described above, the liquidity shock decays at a rate of 85% per quarter.

The responses are expressed as percentage deviations from their respective steady states. After

Figure 1: Impulse responses after a liquidity injection to banks



This figure shows impulse responses after a liquidity injection shock to banks which is equal to 5% of GDP. The solid line represents responses when only the domestic central bank introduces this shock. The dashed line represents responses when both the domestic and foreign central bank introduce liquidity injections. The responses are expressed as percentage deviations from their respective steady states. "D" stands for domestic economy and "F" for foreign economy.

a non-coordinated liquidity injection, the exchange rate declines which means it appreciates[9] in the first two periods by 0.42% but depreciates persistently thereafter. In this model the exchange rate is determined by the terms of trade ($tot_t = P_t^*/P_t$) that is the relationship between export (P_t^*) and import prices (P_t). Figure 1 shows that in the first two periods liquidity injections lead to an increase in domestic export prices while prices in the foreign economy (import prices) decline. Prices increase due to the increase in credit supply which in turn increases GDP and domestic demand. Prices in the foreign country decline amid the symmetry of the countries and the complete international asset market structure of this model with its consequent risk sharing assumption $e_t^r = \frac{\lambda_t^*}{\lambda_t}$ (see equation (6)). This interaction in prices is mirrored in the response of the domestic trade balance. It is negative as long as import prices are lower than export prices, leading to higher demand for imports. It is turning positive as soon as export prices are below import prices. From the behavior in the banking sector we see that liquidity injections lead to a substantial increase in credit supply to firms (+20%) in the domestic economy which in turn boost GDP in the first period by more than 2.5%. However the shoot up in credit is not persistent and falls below its steady state after 5 periods as banks have to pay back the liquidity injections. Carried by a positive trade balance in the long run, GDP returns to its steady state after 10 periods. Liquidity injections in the domestic economy transmit to the foreign economy through the risk sharing condition. Since both countries are symmetric, the opposite is happening in the foreign economy. Loans to firms (-10%) and GDP (-1%) decline.

When both central banks introduce liquidity injections simultaneously (dashed line) variables in

[9]The exchange rate is defined in terms of the domestic currency, e.g. if the domestic currency is given in US Dollar and we assume the exchange rate is 1.35, meaning that Euro is worth 1.35 US Dollars, then if the exchange rate declines to 1.2 US Dollars that means that the US Dollar appreciated or that the Euro depreciated.

both countries will have the same response to the shock due to the complete structure of the international market. Thus, the exchange rate, terms of trade, export and import prices, and the trade balance do not move. Now we see the same responses in both economies, loans to firms increase (but only by half as much as in the case of non-coordination) leading to a slightly lower impact on GDP which increases by about 1.5% in the first period instead of 2.5% as in the case of non-coordination. Also, domestic GDP falls below its steady state after eight periods whereas under non-coordination it remained above its steady state for 10 periods.

Figure 2: Present value of GDP after a liquidity shock

Domestic Economy

Foreign Economy	Liquidity Injection	No Liquidity Injection
Liquidity Injection	+6.52% +6.52%	-4.5% +11%
No Liquidity Injection	+11% -4.5%	- -

Results for the domestic economy are in the upper right corner of each box.

Figure 3: Discounted inflation deviations after a liquidity shock

Domestic Economy

Foreign Economy	Liquidity Injection	No Liquidity Injection
Liquidity Injection	+0.072% +0.072%	+0.01% +0.073%
No Liquidity Injection	+0.073% +0.01%	- -

Results for the domestic economy are in the upper right corner of each box.

In Figure 2, I compare the discounted deviations in GDP from their steady state and in Figure 3, I look at the discounted root mean squared deviations of inflation in the case of coordination and non-coordination. By computing the present values of these deviations I follow the approach of Angeloni et al. (2010), this allows me to sum up the intertemporal effects of various unconventional measures in one indicator[10]. The observation that GDP in the domestic country is higher in the case of non-coordination is confirmed by the present values. If the domestic central bank wants

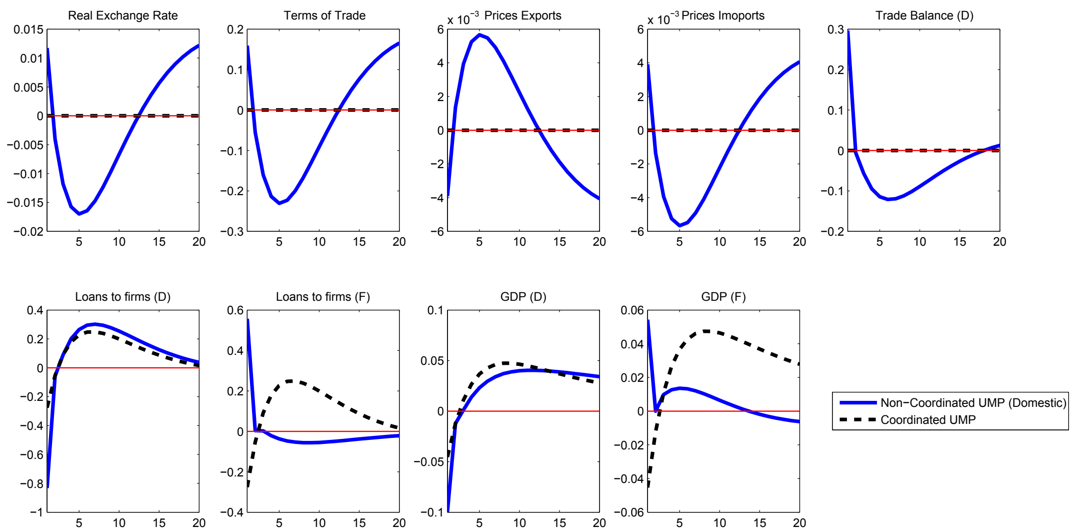
[10] The present value is computed by taking the deposit rate as a discount factor over a horizon of 20 periods. For GDP: $\frac{\sum_{t=1}^{T}\beta^t(gdp_t - gdp)}{gdp}$. For inflation variation: $\left(\frac{\sum_{t=1}^{T}(\pi_t-\pi)^2}{T-1}\right)^{\frac{1}{2}}$

to increase GDP, higher output increases over time can be attained with non-coordination (+11% vs. +6.52%). However, in the case of non-coordination, GDP in the foreign economy will be considerably lower (-4.5%) due to the decline in credit supply and the negative trade balance. This leads to the suggestion that the foreign economy should immediately use liquidity injections when it observes the domestic economy using this measure. With regard to inflation, Figure 3 shows that liquidity injections also increase fluctuations in inflation. When only one or both countries are using liquidity injections inflation variation increases by 0.07%. In the case of non-coordination, inflation variation will be higher in the country with liquidity injections with some inflation fluctuations spilling over into the other economy.

4.1.2 Asset swaps

Figure 4 shows an asset swap shock to lending banks which is equal to 5% of GDP. In comparison to a liquidity shock, the asset swap shock differs strongly in direction and magnitude but is more persistent. This is due to the modeling of the asset swap shock. Note that the asset swap enters the profit function of lending banks only in time t, as I assume that the lending banks are swapping a fraction of loans against assets immediately, there is no intertemporal effect. Furthermore, the balance sheet of lending banks is not increasing (like for liquidity injections where they get additional funds) but it is altered in its composition, i.e. quality, this is why the impact is lower in comparison to liquidity injections but more persistent.

Figure 4: Impulse responses after an asset swap shock to banks



This figure shows impulse responses after an asset swap shock to banks which is equal to 5% of GDP. The solid line represents responses when only the domestic central bank introduces this shock. The dashed line represents responses when both the domestic and foreign central bank introduce liquidity injections. The responses are expressed as percentage deviations from their respective steady states. "D" stands for domestic economy and "F" for foreign economy.

When only the domestic lending banks are able to swap loans against central bank bonds, the exchange rate depreciates for one period and appreciates thereafter. This is due to the impact of asset swaps on export and import prices and thus on the terms of trade. Assets swaps cause a

Figure 5: Present value of GDP after an asset swap shock

		Domestic Economy	
		Asset Swaps	No Asset Swaps
Foreign Economy	Asset Swaps	0.60% 0.60%	0.13% 0.47%
	No Asset Swaps	0.47% 0.13%	- -

Results for the domestic economy are in the upper right corner of each box.

decline in credit supply thereby absorbing liquidity and decreasing demand which causes a decline in prices. Thus after a non-coordinated asset swap, export prices decline for one period while import prices increase. This in turn, leads to a positive trade balance in the first period as domestic exports are cheaper than foreign exports. This effect is reversed in the second period when credit supply starts to grow slowly. The impact of asset swaps on the quality of banks assets is built over time rather than instantaneously. Since in each period (as long as the asset swap shock prevails) banks are able to swap only a fraction of their “bad assets”, they are only able to increase loan supply in the next period by a fraction. Thus banks need several periods to increase loan supply above its steady state. Loan supply needs about three periods to increase above its steady state; the same time GDP needs to increase above its steady.

Amid the risk sharing condition, the opposite is happening in the foreign economy. Credit supply to foreign firms increases slightly in the first period and persistently declines thereafter. This initial increase in credit triggers an increase in output. However in the following period GDP declines immediately to its steady state but only to increase again in the third period, this time driven by a positive trade balance. Foreign output remains above its steady state as long as foreign prices are below domestic prices.

When turning to the assessment of the impulse responses in the case of coordination (dashed line), we see that amid the complete international market assumption real exchange rates, terms of trade, export and import prices, and the trade balance do not move since both countries are experiencing the exact same shock at the same time. Then impulse responses in the domestic and foreign economy move in the same way, credit supply decreases initially in both countries (but not as strong as in the case of non-coordination) leading to declines in GDP but this time declines in domestic GDP are not as high as in the case of non-coordination since the negative trade balance is circumvented under coordination. Although foreign GDP is now decreasing in the first period as well, the comparison of present values of GDP deviations under coordination and non-coordination in Figure 5 reveals that both countries can attain higher GDP increases over time if they coordinate asset swaps. Even if countries do not coordinate asset swaps, the other economy will experience positive spillovers on GDP, as assets swaps lead to positive trade balances in the foreign economy and thus to higher GDP. In the case of inflation (Figure 6), both countries

Figure 6: Discounted inflation deviations after an asset swap shock

Domestic Economy

Foreign Economy		Asset Swap	No Asset Swap
	Asset Swap	+0.0032% (domestic) +0.0032% (foreign)	+0.00038% (domestic) +0.0035% (foreign)
	No Asset Swap	+0.0035% (domestic) +0.00038% (foreign)	- -

Results for the domestic economy are in the upper right corner of each box.

are able to attain a slightly lower inflation variation when policies are implemented simultaneously since under coordination the fluctuation in export and import prices is avoided.

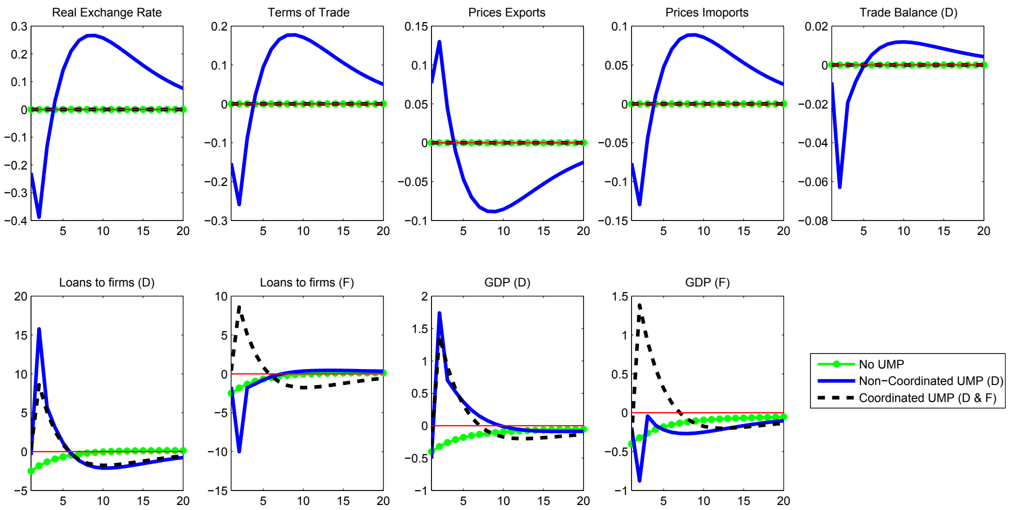
4.2 Experiments

In this section I analyze the ability of both unconventional measures to moderate downturns in economic activity after a negative market book shock. The market book shook is equal to the one used by deWalque et al. (2010) and is supposed to mitigate the beginning of the financial crisis where banks experienced large losses in their market book after investments in mortgage backed securities devaluated dramatically, resulting in a credit crunch. In my model, the market book shock is equivalent to a sudden decrease in market book returns : $\rho_t = (1 - \rho_{rho}) * \bar{\rho} + \rho_{rho} * \rho_{t-1} - u_t^{\rho}$ with ρ_{rho} equal to 0.5 and a standard deviation of 0.1. This means that it takes about a year for the shock to disappear. In both experiments the setup is the following: In the first period both economies, domestic and foreign, are hit by this strong negative market book shock. In the second period there is either no intervention, or only the domestic, or both central banks intervene and either inject liquidity or allow for asset swaps. In order to model this experiment in Dynare, I have to compute the impulse responses within a deterministic setup. This means, that agents have full foresight. This is arguably a strong assumption, however when comparing the impulse responses with the ones under the stochastic setup (as described in section 4.1) the impulse responses move in the exact same direction and differences are marginal. Moreover, in Gieck and Traczyk (2010), we show that the difference in results between a stochastic and a deterministic setup for this model in a closed economy setup is very small.

4.2.1 Negative Market Book Shock: Liquidity injections

Figure 7 presents impulse responses for three different scenarios. In the first scenario, No UMP, there is a negative market book shock in both countries which decreases the return on the market book of banks by 200 percent (so it becomes negative). In the second scenario, Non-Coordinated UMP, only the domestic central bank intervenes in the second period with liquidity injections (solid line) which are equal to 5% of GDP. In the third scenario, Coordinated UMP, both central banks intervene in the second period with liquidity injections (dashed line).

Figure 7: Impulse responses after a negative market book shock in the 1st period with and without liquidity injections in the 2nd period



This figure shows impulse responses after a negative market book shock which is equal to one standard deviation. The dotted line represents responses with no interventions by the central banks after the shock occurred. The solid line shows responses when only the domestic central bank is injecting liquidity to banks in the 2nd period. The dashed line represent responses when both the domestic and foreign central bank are injecting liquidity to banks in the 2nd period. “D” stands for domestic economy and “F” for foreign economy.

Figure 8 shows that the negative market book shock leads to a credit crunch, banks reduce their loan supply to firms which in turn leads to a decrease in GDP. GDP in both countries declines by 0.47% in the first period and remains below its steady state for the remaining 19 quarters. Loans decrease by -2.36% in the first period and remain below their steady state for 10 quarters. Since both countries are symmetric the exchange rate and terms of trade do not move as both countries experience the same market book shock at the same time. The blue solid line shows that if only the domestic central bank intervenes with liquidity injections after the market book shook it can mitigate a credit crunch. Loans to firms increase substantially and thereby stimulate GDP. Liquidity injections lead to increases in export prices which lead to an appreciation of the real exchange rate of the domestic economy. These increased prices cause a decline in exports and thus a negative trade balance for 5 periods. In the foreign country, the increased demand for foreign goods initially accelerates economic activity but due to depreciation of the domestic exchange rate in the long run the demand for foreign goods weakens which leads to a persistent decrease in foreign GDP. When both central bank coordinate policies and inject liquidity after observing the market book shock, the black dashed line shows that both countries can avoid a credit crunch but in that case GDP in the domestic economy is not increasing as much as it would under non-coordination. The impulse on loans and GDP under coordination is lower than under non-coordination, as the expected positive impact on GDP through a surplus in the trade balance is not possible in the case of coordination.

Figure 8 confirms the results from the impulse responses, in that liquidity injections can moderate declines in GDP substantially. But it also shows that the domestic economy would achieve

Figure 8: Present value of GDP after a market book shock and subsequent liquidity injections

Foreign Economy	Domestic Economy: Liquidity Injection	Domestic Economy: No Liquidity Injection
Liquidity Injection	+0.91% +0.91%	-4.29% +2.51%
No Liquidity Injection	+2.51% -4.29%	-2.59% -2.59%

Results for the domestic economy are in the upper right corner of each box.

the highest increases in GDP if it does not coordinate liquidity injections with the foreign economy (+2.51%). Then the decline in GDP for the foreign economy would be even higher (-4.29%) than in the case with no interventions by both central banks (-2.59%). Thus, the foreign central bank should also inject liquidity after a market book shock if it observes that the domestic central bank is using this measure. Figure 9 shows that liquidity injections increase inflation variation. In the case of non-coordination they even lead to slightly higher variations in the other economy's inflation (after a market book shock) as it is forced to adjust. If both central banks coordinate interventions they receive higher inflation variations than in the case of no interventions as liquidity interventions generally increase fluctuations in inflation.

Figure 9: Discounted inflation deviations after a market book shock and subsequent liquidity injections

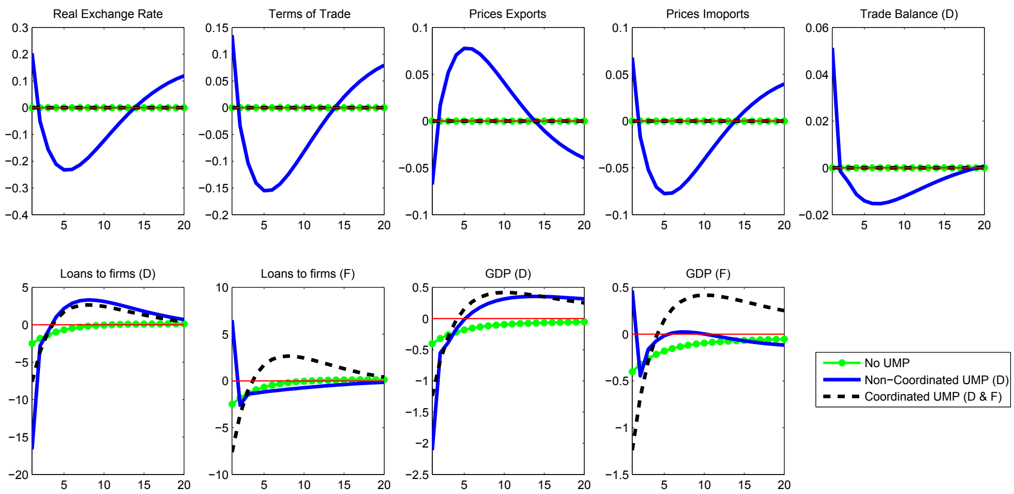
Foreign Economy	Domestic Economy: Liquidity Injection	Domestic Economy: No Liquidity Injection
Liquidity Injection	+0.1% +0.1%	+0.09% +0.08%
No Liquidity Injection	+0.08% +0.09%	+0.07% +0.07%

Results for the domestic economy are in the upper right corner of each box.

4.2.2 Negative Market Book Shock: Asset swaps

Figure 10 shows impulse responses for three different scenarios, (i) either none (dotted line), (ii) or only the domestic (solid line), (iii) or both central banks (dashed line) introduce asset swaps in

Figure 10: Impulse responses after a negative market book shock in the first period with and without asset swaps in the second period



This figure shows impulse responses after a negative market book shock which is equal to a decline in banks' returns by 200%. The dotted line represents responses with no interventions by the central banks after the shock occurred. The solid line shows responses when only the domestic central bank is carrying out assets swaps in the second period. The dashed line represents responses when both the domestic and foreign central bank are carrying out assets swaps in the second period. "D" stands for domestic economy and "F" for foreign economy.

the second period which are equal to 50% of GDP[11] after the return on the market book of banks declines by 200%. The impulse responses show that assets swaps have also the ability to increase credit supply and GDP after a market book shock. However only in the long run, not instantly like in the case of liquidity injections. Moreover, the impact of asset swaps is less pronounced compared to quantitative measures as also seen in section 4.1.1. In the case of coordination, the dashed line shows that domestic GDP not only passes its steady state one period earlier than in the case of non-coordination but the rise in GDP is also higher. This is due to the impact on lending, if both countries coordinate asset swaps initial decreases in domestic loans are lower than in the non-coordinated case.

Figure 11 shows that asset swaps if non-coordinated are able to moderate decreases in present value GDP from -2.59% to 0.57%. And even in the case of non-coordination, the foreign economy benefits from the positive spillovers on its economy in terms of lower GDP declines (-2.7%) due to the positive trade balance in the foreign economy. However, the strongest impact assets swaps develop in the case of coordination leading even to positive increases in GDP after a negative financial market book shock. And the same is true for inflation (Figure 12), the lowest inflation variation is reached when central banks coordinate asset swaps (+0,056%) since asset swaps absorb liquidity.

[11]For visibility reasons I had to increase asset swaps to 50% of GDP. If assets swaps would be equal to 5% of GDP (like liquidity injections), the impact would be hardly visible in the impulse responses compared to the market book shock.

Figure 11: Present value of GDP after a market book shock and subsequent asset swaps

Foreign Economy \ Domestic Economy	Asset Swaps	No Asset Swaps
Asset Swaps	-2.08% (domestic) -2.08% (foreign)	-2.41% (domestic) -2.261% (foreign)
No Asset Swaps	-2.26% (domestic) -2.41% (foreign)	-2.59% (domestic) -2.59% (foreign)

Results for the domestic economy are in the upper right corner of each box.

Figure 12: Present value of inflation after a market book shock and subsequent asset swaps

Foreign Economy \ Domestic Economy	Asset Swaps	No Asset Swaps
Asset Swaps	+0.056% (domestic) +0.056% (foreign)	+0.056% (domestic) +0.056% (foreign)
No Asset Swaps	+0.056% (domestic) +0.056% (foreign)	+0.074% (domestic) +0.074% (foreign)

Results for the domestic economy are in the upper right corner of each box.

5 Conclusion

Unconventional measures while viewed as helpful and expansionary to the country where they are applied, are viewed with suspicion by foreign counterparts, even declared as weapons in a "currency war" between nations as they are commonly believed to depreciate the currency of the applying economy and thereby boosting its exports. However, empirical literature shows contradictory results, in that unconventional measures not always depreciate the currency and that different unconventional measure can lead to different outcomes (see Fratzscher et al. (2012), Honda et al. (2007)). Literature which tries to address this question from a theoretical standpoint by using a DSGE model with an interbank market is thin, since it was broadly assumed that financial agents do not mater due to the Modigliani-Miller theorem. The financial crisis dramatically showed the relevance of financial institutions and their importance in the transmission of monetary policy especially unconventional monetary policy. For this reason, it is important to address the question of the impact of unconventional measures on the exchange rate in a model with a meaningful interbank market imbedded in a two country economy.

In this paper I therefore propose an open economy model with an interbank market to analyze the impact of various unconventional measures on the exchange rate. I document that different unconventional monetary policy measures do affect the exchange rate differently. In my model liquidity injections lead to an appreciation of the exchange rate in the short run but to a depreciation in the long run and the opposite is true for assets swaps (depreciation in the short run, appreciation in the long run). This is due to the impact of liquidity injections on the economy which lead to an increase in credit supply and domestic demand in the short run thus raising domestic prices and through the terms of trade appreciating the domestic currency. This effect, however, is reversed in the long run; as soon as credit supply starts to decrease, domestic prices start to decrease as well causing a depreciation of the domestic exchange rate which in turn leads to a positive trade balance in the domestic economy thereby lifting domestic output while foreign output is depressed. Asset swaps have the contrary impact on the exchange rate, in the short run they absorb liquidity leading to a decline in prices and thus to an depreciation but in the long run they cause an appreciation of the exchange rate as they increase credit supply and prices which leads to a negative trade balance and lower growth. My results for the behavior of the exchange rate in the short run, are in line with recent empirical findings see Fratscher et al. (2012), while my long run results are in line with the general economic and political debate in terms of currency wars. Furthermore, my paper shows that unconventional measures can have significant negative spillovers on other economies in terms of negative trade balances and thus lower GDP growth as well as increased variations in inflation. These results support the critical view of foreign country representatives on the excessive usage of unconventional measures, especially in the case of liquidity injections, which in my model result in higher GDP rates in the country where they are applied but lead to decreases in economic activity in the other country when non-coordinated. This results leads to the conclusion that the other country should also inject liquidity when it observes a country (with which it has substantial trading relations) applying this measure. Asset swaps, on the contrary, unfold the strongest impact when coordinated. And even in the case of non-coordination, they still have positive spillovers on the other economy. Another result of this paper is that liquidity injections better mitigate negative effects from a financial shock than asset swaps. While it is sufficient to inject liquidity as high as 5% of GDP to mitigate negative effects, asset swaps need to be substantially higher to see the same change.

This paper contributes to the question of exchange rate behavior and coordination of unconventional monetary policy in an international environment. It has important implications for the implementation of unconventional measures and can contribute to the debate on “currency wars”. It also provides a versatile model which could be altered in various directions to be useful for related research questions such as the exit from unconventional measures.

6 Appendix

Table 2.1: Calibrated Parameters

Parameters[12]	Description	Values
$\bar{r}$	target rate in deposits	0.0035
β	discount factor	0.9965
η	elasticity of substitution	1.5
$1-\gamma$	trade openness	0.2
$\bar{m}$	leisure utility parameter	3.14
$\bar{D}^{l}$	target in deposits	0.39
χ	deposit gap disutility	0.216
N	employment	0.2
μ	capital share	0.3
δ	capital depreciation	0.03
Ψ	capital producer's variable default cost	103.04
d_c	capital producer's fixed default cost	0.001
θ	price elasticity of demand	6
υ	price adjustment cost parameter	17.5
ρ_a	autoregression coefficient in technology equation	0.95
k	own funds ratio	0.08
$\widehat{w}$	Basel weight for loans to banks rating AAA to $AA-$ (S&P)	0.2
$\widetilde{w}$	Basel weight for loans to enterprises rating A+ to A- (S&P)	0.5
ρ	return on market book	0.02
$\upsilon_{db}=\upsilon_{lb}$	profit share allocated to own funds	0.5
ξ_{db}	share of own funds devoted to insurance fund (deposit bank)	0.07
ξ_{lb}	share of own funds devoted to insurance fund (lending bank)	0.06
$\zeta_{db}=\zeta_{lb}$	insurance coverage on defaulted amount of banks	0.8
ω	lending bank's default cost	174
$d_{F^{db}}$	utility of own funds (deposit bank)	24.58
$d_{F^{lb}}$	utility of own funds (lending bank)	27.71
$\bar{B}^{db}=\bar{B}^{lb}$	market book volume of banks	0.19
ρ_M	autoregression coefficient for liquidity injections	0.85
ρ_X	autoregression coefficient for asset swaps	0.85
Q_π	Taylor reaction to inflation	1.7
$\overline{\pi}$	inflation target	1
μ_r	policy inertia	0.8

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