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Monetary Policy Under a Currency Board

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Abstract

The consensus view is that central banks under currency boards do not have tools for active monetary policy. In this paper, we analyze the foreign exchange fee as a monetary policy instrument that can be used by a central bank under a currency board. We develop a general equilibrium model showing that changes in this fee may have the same effects as a change in the monetary policy stance. Thus central banks under the currency board are shown to have an avenue to implement active monetary policy.

1 Introduction

The consensus view is that central banks under currency boards do not have tools for active monetary policy. In such a regime, all liabilities of the central bank, including money in circulation, must be fully backed by foreign reserves. Therefore, the usual monetary policy channel of changing the target interest rate through changes in the money supply is incompatible with the constraints imposed by the currency board arrangement, because issuance of new money in circulation must always be met by an equivalent increase in foreign reserves.

Countries that adopt a currency board regime give up active monetary policy and implement a credible currency peg to a trusted reference currency. Through such an arrangement, inflation rates of the reference currency country are "imported" to the domestic economy. Thus, the currency board regime is an attractive option for a country with chronically high inflation. It is also used as a speedy trust-building mechanism for introduction (or reintroduction) of national currencies (e.g., post Soviet transition economies).
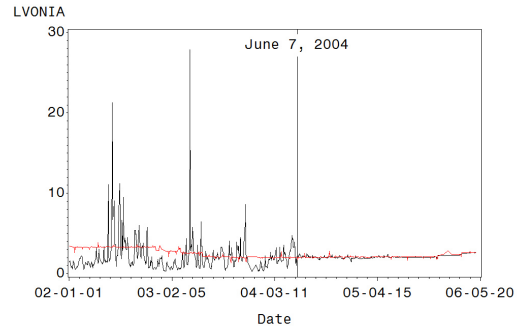
Under the currency board, central banks exchange the base currency on demand, thus creating effective bounds on the interbank market interest rate fluctuations, similar to the standing facilities of independent central banks (e.g., deposit and lending facilities of the European Central Bank). If domestic interbank market interest rates differ sufficiently from the base currency interbank market interest rates, profitable arbitrage opportunities arise. Thus, domestic interbank market interest rates fluctuate within the band of the transaction costs of engaging in the foreign interbank market.

Acknowledging the fact that there are other costs (e.g., difference due to transaction execution time), the bounds of interest rate fluctuation largely depend on the base currency interest rate and the foreign currency exchange transaction fee charged by the central bank. If this fee is diminished, no-arbitrage deviations from the base currency interest rate become smaller, and we will observe domestic interest rates that are closer to the base currency interest rate. Recently some central banks in currency board countries have changed their policy regarding the fee charged for exchanging the base currency at the central bank. In mid-2004, the central banks of Bulgaria and Lithuania decreased the fee charged for exchanging base currency. As shown in the Figure 1, this change diminished the interbank market interest rate fluctuations significantly and simultaneously increased base currency exchange transaction volumes. In this paper, we focus on investigating the possible effects of a change in the foreign exchange transactions fee on the real side of the economy of a currency board country.

To the best of our knowledge, there is no literature investigating the effects of limiting the fluctuation of interbank market interest rates in currency board countries. There is some literature, however, investigating the effects of monetary policy of an independent central bank within a channel system. A channel system is a monetary policy regime where the central bank introduces mechanisms
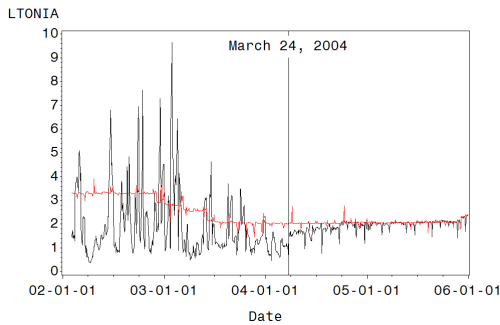
(a) Lithuania: Litas overnight index average   (b) Bulgaria: Leva overnight index average

Figure 1: Interbank interest rates: domestic market interest rate with respect to base currency interest rate fluctuations (EONIA)

through which short-term interest rates are contained within a channel given by a target interest rate and possible fluctuation bounds. Quirós and Mendizábal (2006) investigate the interbank markets of the European Monetary Union, building a model with features of a channel system of the monetary policy. They show that, due to the availability of standing facilities, interest rates fluctuate within the reserve holding period and tend to be higher towards the end of it. Jurgilas (2005) shows that interbank markets under currency boards have similarities to the channel system monetary policy of independent central bank, because the currency exchange window of the central bank in a currency board introduces de facto standing facilities. Jurgilas (2006) points out that, under the currency board, the evolution of interest rates within the reserve holding period depends on the aggregate liquidity in the market. Recently, Berentsen and Monnet (2007) built the first general equilibrium model explaining the mechanism of a channel system of monetary policy. They find that the central bank can alter a monetary policy stance, changing the bounds of possible interest rate fluctuations, without changing the target interest rate. In their model, the cost of providing collateral for secured loans, together with the uncertainty regarding future consumption and production, drives the activity in the interbank market and use of the standing facilities.

We extend the current literature in several aspects. First, we provide a stylized framework for analyzing channel system monetary policy under a currency board. Second, we show that, under certain conditions, central banks operating in the currency board may have an avenue to implement active monetary policy. Since central banks under the currency board do not have the usual monetary tools of an independent central bank, this may prove to be an important addition to their limited policy choices. Finally, a general equilibrium model is developed, allowing us to evaluate different scenarios under which changes in the foreign currency exchange fee may have an impact on the economy. We focus our study on the effects of a change in the fee policy on the real side of the

economy and on the risk profile of investments. As we show, there are conditions under which variability of interest rates matters and those under which imposing fluctuation bounds does not have any real effects.

It may be argued that, as the costs of liquidity management are diminished, banks will have an incentive to undertake more risk in picking their investment projects. We investigate this possibility trying to see if, as the uncertainty of the interest rate diminishes, there is a change of investment portfolio allocations towards riskier investment.

The rest of the paper is structured as follows. In Section 2 we lay out the environment of a general equilibrium model. Section 3 presents the model and general solution methodology. Section 4 shows the simulation results, and Section 5 concludes. Robustness checks and a possible extension of the model are presented in the Appendix.

2 Model environment

2.1 Motivation

We develop a stylistic model of the interbank market under a currency board. As empirical evidence suggests, (e.g., Prati et al. (2003), Jurgilas (2005), Quirós and Mendizábal (2006)), interbank market interest rate fluctuations largely can be explained by changes in aggregate liquidity in the market. There could be multiple reasons for a change in demand (or availability) of funds. A natural explanation in the case of an independent central bank is a monetary policy shock. But under a currency board, central banks do not conduct active monetary policy; there is no intervention in the money market unless initiated by the banks themselves, through the use of the currency exchange window.

The main building block of our model is the assumption that changes in liquidity demand are related to changes in household income. As households experience a positive income shock, their consumption demand increases. Assuming that consumption of some goods requires liquid assets, this creates a shock to liquidity demand. We model income shocks as arising due to shocks in productivity, thus relating liquidity demand with the productive side of economy. There is no money because our focus is on the real effects of a change in policy.

The currency board environment is implemented assuming that commercial banks are capable of participating in the foreign currency interbank markets if profitable arbitrage opportunities as described above arise. Thus, the domestic interbank market interest rate fluctuates within the band, the width of which is a policy variable of the central bank. That is the main policy parameter of interest in our model.

The motivation to investigate this policy variable comes from recent changes in foreign currency

transaction costs by several central banks in Eastern Europe, who have shown that they have a preference for a smaller interest rate band. Through public announcements, central banks have rationalized this change in policy with an intention to bring domestic market interest rates closer to the reference currency interest rates. That seems to be motivated by the fact that some of these countries are on the path of adopting the base currency (e.g. Estonia, Lithuania, and Bulgaria, which are all currency board countries). Unfortunately, the bid to join the European Monetary Union (EMU) did not fare well with some of them. Ironically, while currency boards were implemented in early 1990s to *control* inflation, Lithuania and Estonia could not join the eurozone due to too high inflation. There is a plethora of explanations for the "too high" inflation (e.g., real convergence, Balassa-Samuelson effect, and bad fiscal policies, to name a few). Unfortunately, there are few monetary policy prescriptions which, given a currency board environment, is not that surprising.

In this context, we provide another explanation as to what could have motivated central banks of the currency board countries to change the foreign currency exchange fee. We argue that lowering these transaction costs was equivalent to tightening monetary policy. This is relevant as, for example, Lithuania missed its inflation target for the EMU. Thus removal of the fee could be seen as a bid to control imported inflation. The model that we develop below provides the logic of our argument.

2.2 Model structure

It is our understanding that the banking markets of the currency board countries that we are set to analyze are very concentrated. The countries are small and usually have a significant presence of big foreign banks. Just to give an example, in its public announcement on the performance of credit institutions the Bank of Lithuania reports that in 2006 the asset market share controlled by the three largest banks was 70%. In Bulgaria, about 73% of the banking system's balance sheet is accounted for by 10 largest banks[1]. In this perspective, allowing for market power in the banking sector seems to be a reasonable assumption.

One of the key assumptions that we make in modeling the liquidity shocks is that different banks are hit with different liquidity shocks due to the segmentation of the bank's depositor base. Intuitively, we can think of regional banks serving households in specific regions. Thus, in our model we choose to model a banking system with a segmented depositor base, although banks are capable of diversifying their investment portfolios across different sectors of the economy.

There are two sectors of the economy producing two goods.[2] The economy is populated with two firms (indexed 1 and 2), two types of households (indexed a and b), two banks (indexed x and y), and the government (Figure 2). This is the most parsimonious framework given the questions that we try to answer.

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[1] Bulgarian National Bank "Commercial Banks in Bulgaria 2006"

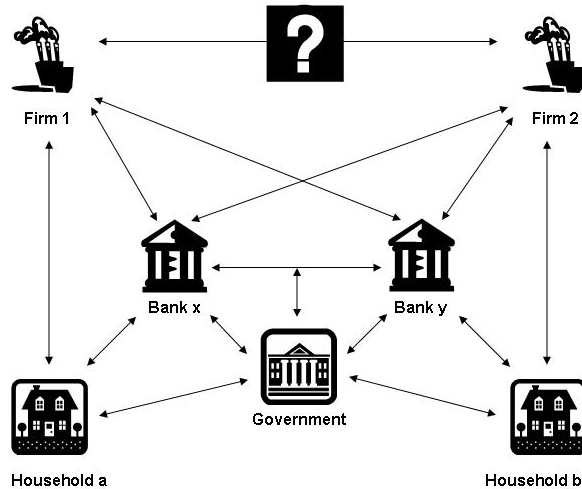[2] We could easily extend the model to include more sectors.

Figure 2: Structure of the model environment

Time is discrete and the life span of agents is T. Each period three markets open sequentially: a goods market, the interbank market, and the financial market (Figure 3). In the goods market, households buy goods produced by the firms. In the interbank market, banks borrow or lend funds that are needed to execute payments. In the financial market, households make savings decisions (e.g., make deposits at the bank, buy bonds issued by the government, and collect interest on past savings), while banks make investment decisions and pay an interest rate on past deposits and interbank loans, and firms pay an interest rate on loans and pay out wages.

Households of type a supply labor inelastically to the 1st firm, and households of type b supply labor to the 2nd firm. We can think of this arrangement as a representation of the two sectors of the economy. Type a households, while working in the 1st firm, produce "apples," while households of type b work in the 2nd firm and produce "bananas." Both types of households consume apples *and* bananas. Each household can purchase on credit the product of the sector in which they are working, while the good produced in the other sector can be purchased only using the household's own goods. Note that during each period consumption decisions are made after income uncertainty is resolved, but before income has been received. Thus, households are constrained by a "goods in advance" constraint.

Banks offer households time deposit contracts, which pay interest if held until maturity. We make an assumption that deposits withdrawn before maturity still receive a fraction of the agreed interest. Households may decide to withdraw a portion of their time deposits in order to acquire goods produced in the other sector of the economy, jeopardizing the interest rate. The only bank that is operating in the 1st sector is bank x. Similarly, bank y is the only bank available for households
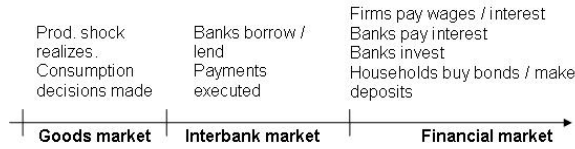
Figure 3: Timeline of one period

b. Although banks are limited in their depositor base, they can invest into both firms to diversify their investment portfolio.

Each period, banks must decide on the amount of reserves that will be held until the next period. The only purpose of holding reserves is to execute payments initiated by households. Thus, the demand for liquidity is driven by households' consumption of the "other" good, which is dependent on income received. The only uncertain part of a household's next period income is the wage paid by the firm. Firms are assumed to work under a zero profit condition and always pay out the marginal product.

Households have two storage technologies available. They can make deposits or buy government bonds. Bonds pay a riskless rate of return. The government operates under the balanced budget condition, taxing the banks appropriately. Thus, taxation has a pure redistributive effect.

An intuitive explanation of the model dynamics is that a positive productivity shock in one sector of the economy leads to a higher marginal product of labor, resulting in a positive shock to a household's income. Unexpected realizations of this shock increase household consumption. Since consumption of some of the goods require liquid assets, households use deposits kept at the bank for payment. This results in a positive liquidity demand shock faced by the bank. If banks fall short in reserves and cannot execute payments, they must borrow in the interbank market. Similarly, if banks end up having excess reserves, they may choose to lend the funds in the interbank market. The central bank sets the foreign currency exchange fee, which limits the domestic interbank market interest rate fluctuations.

We assume that each bank solves a dynamic problem, taking the response functions of the households into consideration. Therefore, in the bank-household relationship a dynamic Stackelberg game is played. Since the two banks are investing in the same firms, we assume that optimal strategies are determined by banks playing a noncooperative game. Thus, given the Stackelberg game each bank plays with a respective household, we are searching for optimal bank strategies that yield Nash equilibrium in every proper subgame: a Markov perfect equilibrium.

3 Model

In this section we provide the formulation of the model assuming that agents live for two periods ($T = 2$). The formulation of the model for infinitely lived agents is provided in Appendix A.

If we make an assumption that agents are infinitely lived, the problem becomes much more complicated and computationally involved. As the major dynamics of the model economy are conveyed with a two period formulation, we leave the solution of an infinitely lived agent formulation for future research.

3.1 Firms

There are two sectors of the economy represented by two firms. Each of the two firms produce one product only. Both firms are assumed to have the same production technology with constant returns to scale:

$$Y_i = A^{z_i} K_i^{\alpha}, \ A > 0, \ i = \{1, 2\}$$

Labor is normalized to 1. K_i denotes capital of the firm i, A is average productivity, while z_i is the productivity shock. Note that we assume that both goods from different sectors of economy are equally productive when used as capital.

Both firms pay the marginal product for factors of production according to the realization of the productivity shock. Thus, firms operate under a zero economic profit condition, regardless of the state of the economy, given by:

$$rl_i = MP_k(z_i, K_i)$$
$$w_i = MP_l(z_i, K_i)$$
$$K_i = k_{xi} + k_{yi}$$

where $i = \{1, 2\}$, K_i denotes the capital level accumulated in firm i, and k_{xi}, k_{yi} denote, respectively, bank x and y's capital holdings in firm i. rl_i denotes return paid on capital, while w_i denotes wage. Productivity shocks experienced by each of the firms can either be "good" (z_i^g) or "bad" (z_i^b), where $i = \{1, 2\}$. z has a joint probability distribution of $\mathcal{P}$. Assuming that the mean of z_i is 1, the average productivity is governed by parameter A. Thus, if a firm is in the "good" state, it pays more, while returns are lower in the "bad" state.

3.2 Households

There is a continuum of two types of households with mass 1 each. Given the current state of the economy, and taking the strategies of the banks and the aggregate behavior of both types of households as given, each individual household type $i = \{a, b\}$ decides on the consumption of

"apples" and "bananas" $((c_{t,ia}, c_{t,ib}))$ at $t = 1, 2$ and allocation of savings (deposits, d_i, and bonds, b_i). There are no savings in the second period since households consume all of their income.

At the beginning of their life, households are endowed with the initial endowments, (Y_a, Y_b), respectively. In the first period, type a households can make deposits with the bank x, d_a, and type b households can make deposits with the bank y, d_b. In the second period, type a households work at the 1st firm while type b households work at the 2nd firm. We assume that households supply labor inelastically $(l = 1)$.

We make an assumption that goods produced in the same sector where a household is working can be purchased on credit, while the good produced in the other sector can only be purchased with the goods stored at the bank. The rationale is that producer of the other sector does not trust a household with which the producer has no relationship, while the employer of the household has an outstanding liability to that household (e.g., wage payment) and thus is willing to sell goods on credit. Therefore, households are faced with "goods in advance" constraints and, apart from the interest income, they have an incentive to hold deposits in expectation of the future consumption of goods produced in the other sector.

As goods are traded for goods, we normalize the price of the good produced in sector a to one, so that ϵ_t represents the relative price of "bananas" in terms of "apples" in period t. The relative price is determined in the goods market, $C_{ab}\epsilon = C_{ba}$, assuming zero net flow of goods from one sector to the other in each period.

Households are assumed to have log separable preferences over two types of goods: goods produced in their own sector of the economy, and goods produced by the other sector:

$$U(c_{t,aa}, c_{t,ab}) = \ln(c_{t,aa}^{\gamma} c_{t,ab}^{1-\gamma}),\ 0 < \gamma < 1,\ t = 1, 2 \tag{1}$$

where $c_{t,aa}$ denotes household a's consumption of the goods produced by firm 1 in period t, and $c_{t,ab}$ denotes household a's consumption of the goods produced by firm 2. The problem solved by a

9

representative household a (household b solves a symmetric problem) is

$$\max_{dh_a} \ln(c_{1,aa}^\gamma c_{1,ab}^{1-\gamma}) + \beta \underset{z}{E} \ln(c_{2,aa}^\gamma c_{2,ab}^{1-\gamma})) \tag{2}$$

s.t.

$$c_{1,aa} + c_{1,ab}\epsilon_1(DH) + d_a + b_a = Y_a \tag{3}$$

$$c_{2,aa} + c_{2,ab}\epsilon_2(DH)(rd_x - rf_x) = d_a rd_x + w_1(z_1, k_{x1}, k_{y1}) + b_a tr \tag{4}$$

$$c_{2,ab}\epsilon_2(DH) \leq d_a \tag{5}$$

$$z \in \{(z_1^b, z_2^b), (z_1^g, z_2^b), (z_1^b, z_2^g), (z_1^g, z_2^g)\}, \text{ with prob. distribution } \mathcal{P} \tag{6}$$

$$dh_a = \{c_{1,aa}, c_{1,ab}, d_a, b_a, c_{2,aa}, c_{2,ab}\} \tag{7}$$

$$DH = \{C_{1,ia}, C_{1,ib}, D_i, B_i, C_{2,ia}, C_{2,ib}\}, \ i = \{a, b\} \tag{8}$$

$$DB = \{rd_j, I_{j1}, I_{j2}, rz_j\}, \ j = \{x, y\} \tag{9}$$

where DH and DB represent aggregate household decisions and decisions of the banks, respectively. Equation (3) represents the budget constraint of the first period. In the first period, given the endowment Y_a, representative household a decides on the consumption of "apples" ($c_{1,aa}$) and "bananas" ($c_{1,ab}$), and the allocation of savings into deposits and bonds (d_a, b_a). Equation (4) represents the second period budget constraint. In the second period, household a collects interest on government bonds, tr, interest rd_x on the deposits held to maturity, and a fraction of the agreed interest, rf_x, on the deposits withdrawn to obtain the goods of the other sector. Depending on the realization of the productivity shock and investment undertaken by banks, households receive wage payments, w_1. Note that second period consumption decisions are made before income is collected, therefore the non-credit good is obtained by tapping into the savings account. Thus, the "goods in advance" constraint is given in Equation (5).

Note that a representative household takes aggregate household decisions DH and bank policy DB as given. Thus, a solution to this problem is household a's optimal policy function $dh_a(DH, DB)$. In equilibrium, decisions of representative household a must coincide with the aggregate decisions of type a households.

3.3 Banks

There are two banks indexed $j = \{x, y\}$ that act strategically in making decisions. Each bank takes the optimal household response functions ($DH_a(DB)$, $DH_b(DB)$), and the optimal policy of the other bank, $db_j = \{rd_j, I_{j1}, I_{j2}, rz_j\}$, into consideration when solving its problem. Banks are assumed to be risk averse and face a portfolio choice problem in terms of investing in two sectors of the economy.

Each bank takes in deposits from its respective households and invests them into productive

capital in both sectors of the economy. Banks do not invest all of the available assets, but keep some as reserves, (rz_x, rz_y), to facilitate payments in the second period. The amount of these payments is uncertain and thus represents the liquidity demand risk. In case of insufficient or excess reserves, banks can borrow or lend reserves on the interbank market at the rate r.

The problem solved by bank x (bank y solves a symmetric problem) is

$$\max_{db_x} \quad E[R] - \frac{\rho}{2} Var(R) \tag{10}$$

$$\text{s.t.}$$

$$
\begin{aligned}
R &= k_{x1}(rl_1 - \delta) + k_{x2}(rl_2\epsilon_2 - \delta) + (d_a - c_{2,ab}\epsilon_2)rd_x \\
&\quad - c_{2,ab}rf_x\epsilon_2 + (rz_x - c_{2,ab}\epsilon)r - b_a tr \\
rz_x &= d_a - I_{x1} - I_{x2} \\
k_{x1} &= k0_{x1} + I_{x1} \\
k_{x2} &= k0_{x2} + I_{x2} \\
db_x &= \{rd_x, I_{x1}, I_{x2}, rz_x\}
\end{aligned}
$$

where rd_x is the deposit rate, I_{x1} is investment into firm 1, I_{x2} is investment into firm 2, and $k0_{xi}$ is the initial capital. Bank x collects interest on capital holdings, (k_{x1}, k_{x2}), and pays interest on deposits held to maturity $(D_a - C_{ab}\epsilon)$ and withdrawn before maturity $(C_{ab}\epsilon)$. If reserves of bank x are insufficient to execute payments initiated by household a, $(rz_x - C_{ab}e \leq 0)$, the bank will obtain liquidity on the interbank market paying interest rate r. Finally, the bank must pay a tax collected by the government. The solution to this problem, $db_x(db_y)$, is bank x's optimum policy given the policy of bank y.

Due to the currency board arrangement, the central bank stands ready to exchange funds into foreign currency at a fixed exchange rate, thus providing banks with an opportunity to borrow or lend funds in the foreign market. Assuming that the world interest rate is r_w, and cumulative percentage costs of exchanging funds to or from foreign currency are f, domestic interbank market interest rates will fluctuate within the $r_w \pm f$ band. The lower the foreign currency exchange costs are, the narrower the interest rate fluctuation band is.

3.4 Equilibrium

The equilibrium in this formulation is defined by (i) household policy functions $dh_i(DH, DB)$, $i = \{a, b\}$, (ii) bank policy functions $db_j(db_{-j})$, where $j = \{x, y\}$, and (iii) relative price ϵ_t and equilibrium interbank interest rate r such that:

- Given optimal bank policy, household policy functions solve the respective representative household's problem as defined in Equation (2);

- Representative household behavior is compatible with the aggregate:

$$DH_i = dh_i(DH, DB), \ i = \{a, b\};$$

- Given optimal household policy functions, bank policy functions solve respective bank problems as defined in Equation (10);

- Optimal bank policy functions yield Nash equilibrium in every proper subgame:

$$DB = NASH\left[db_x(db_y), db_y(db_x)\right];$$

- Goods and interbank markets clear.

Since the two banks act strategically in choosing their policy, equilibrium optimal bank policies are defined by a Markov perfect equilibrium.

In equilibrium, banks will find it optimal to set the deposit interest rates high enough so that households do not invest in bonds. Thus, the interest rate on government bonds effectively acts as an anchor point for the deposit rates. While the interest rate on government bonds is exogenous in this framework, we do not treat it as a policy variable.

4 Simulation

We are solving a two period general equilibrium model with strategic agents: two followers, and two dependent Stackelberg leaders who play a Nash game between themselves. Nie et al. (2006) developed a solution methodology for a dynamic Stackelberg game with dependent followers. In our case, followers (i.e., representative households) make decisions independently, although decisions of the leaders (i.e., banks) are interdependent.

4.1 Proposed solution algorithm

Due to the complex game theoretic structure, this model does not have a closed form solution, and therefore we have to resort to computational methods. Building on the proposed solution techniques developed by Ambler and Paquet (1997) for a general equilibrium dynamic Stackelberg game, and Nie et al. (2006) in the case of dependent followers, we propose the following solution method:

- Guess optimum decisions of the banks (db_x, db_y);

- Guess aggregate household decisions (DH_a, DH_b);

- Given bank and aggregate household decisions, solve the representative household problem given in Equation (2);

- If the solution of the representative household problem differs from the aggregate household decisions update the aggregate household decisions (DH_a, DH_b) until convergence;

- Given aggregate household decisions solve the bank problem given in Equation (10); and

- If optimal bank decisions differ from the ones assumed, update.

We perform a simulation under different scenarios, changing the parameters of interest. The main parameter in which we are interested is the foreign exchange cost f.

4.2 Calibration

Model parameters are presented in Table 1. We set the discount rate (δ) at 10%, the share of capital in production (α) at 0.4, average productivity (A) at 2, the share of goods purchased on credit (g) at 0.5, risk averseness of the banks, (ρ) at 2, discount rate (β) at 0.95, initial household endowment (Y) at 20, and the fraction of the interest rate paid on prematurely withdrawn time deposit, (fr), at 0.1.

δ	α	A	g	ρ	β	tr	Y	fr	ϕ
0.1	0.4	2	0.5	2	0.95	1.07	20	0.1	0.1

Table 1: Model parameters

The productivity shocks (z_i) can take two values, "good" ($z_i^g > 1$) and "bad" ($z_i^b < 1$), which are varied to explore different standard deviations while maintaining average productivity: $A = (A^{z_i^g} + A^{z_i^b})/2$. Productivity shocks in the two sectors of economy are negatively correlated, thereby simulating various return uncertainties. If not specified otherwise, $z_i^g = 1.1$. The probability of different states of the world is given by the probability distribution:

$$\mathcal{P} = \begin{pmatrix} 0.2 & 0.3 \\ 0.3 & 0.2 \end{pmatrix}$$

Due to the discreteness of the shocks, the bank return function is discontinuous, as the interbank interest rate is either at the maximum or the minimum of the interest rate fluctuation channel. This creates significant difficulty for the numerical maximization algorithm. For the purpose of tractability, we find it appropriate to eliminate the discontinuity by assuming the equilibrium interest rate fluctuates within the interest rate channel (although very elastically), depending on the aggregate excess reserves in the market. As shown in Figure 4, if excess reserves differ from 0 the interbank market rate does not jump discontinuously from the upper bound to the lower bound, but rather varies according to an assumed linear relationship: $r = r_w - \frac{er_x + er_y}{\phi}$. Note that qualitative results do not depend on the specific value of this parameter. We set ϕ at 0.2, which can be interpreted

that if, in aggregate, banks hold 1% excess reserves, the interbank interest rate would drop by 5 basis points. If there are no excess reserves in the market, interest rate equals r_w.
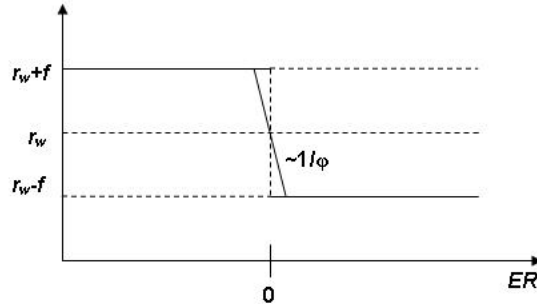

Figure 4: Equilibrium interbank interest rate as a function of excess reserves.

4.3   Simulation results

In this section we present our simulation results and show how changing the variability of the interbank market interest rates affects the economy. We also present robustness checks showing that the qualitative results are insensitive to different parameter values.

Equilibrium deposit interest rate

As can be seen from the household problem in Equation (2) and the bank problem in Equation (10), if banks offer households deposit rates below the government bond rate, households will find it optimal to hold a share of their savings in bonds. But due to the extra benefit of holding deposits (i.e., the possibility of obtaining goods produced in the other sector), households will still hold deposits.

Note that banks choose their policy by taking the response of the households into consideration. It appears that the marginal benefit of households holding fewer bonds than deposits is always outweighed by the associated costs (e.g., government taxes). Thus, both banks find it optimal to set their deposit rate just above the treasury rate. This simplifies the problem to be solved, since the deposit rate can be imposed exogenously.[3]

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[3]In case there is no government and households do not have alternative savings technology, the equilibrium interest rate goes to zero. Thus, the only purpose served by having government bonds in the model is to impose a deposit interest rate that is greater than 0.

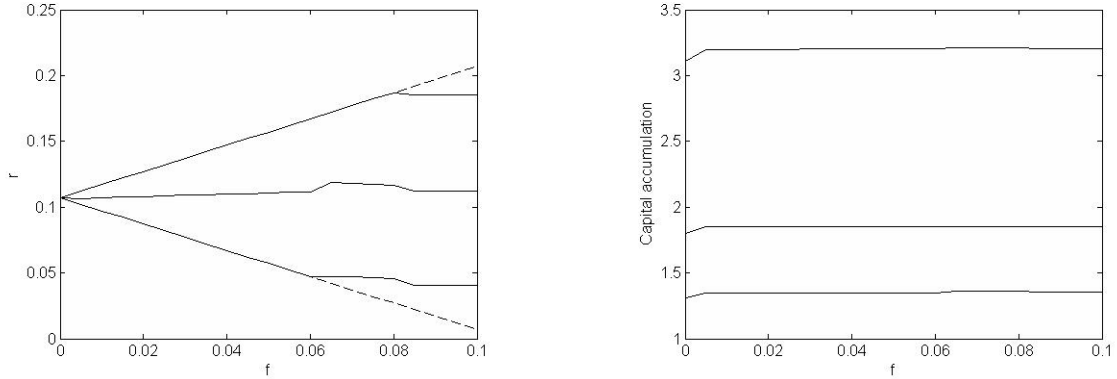**Domestic interbank market interest rate**

Given the parametrization in Table 1, we start out simulating our economy assuming that interest rate channel bounds $r_w \pm f$ are not binding. This is equivalent to assuming that there is no access to the foreign market or that the foreign exchange transactions costs are very big. The equilibrium interest rate obtained given this assumption is called the *natural* interest rate ($\bar{r}$) and is due to the specific parametrization of the model. Given the discreteness of the productivity shocks we obtain a vector of equilibrium interbank market interest rates, corresponding to different states of the world. We obtain the natural equilibrium interest rate assuming $z_i^g = 1$ (no uncertainty regarding productivity).

There is no reason to assume that this interest rate will be equal to the foreign money market interest rate. It might be the case that the currency board country is a transition economy and still has capital accumulation levels below the "foreign" level, or that its economy is experiencing an excess or shortage of liquidity due to an influx of foreign aid or adverse economic shocks. Thus, we allow for a possibility that $\bar{r} \neq r_w$. Or in other words, it could be the case that interbank market interest rates of a currency board country are, on average, higher or lower than the base currency money market interest rate. As can be seen in Figure 1, for quite some time interest rates in Lithuania lingered below the euro interest rates.

Effects of lower exchange rate costs

We simulate our model economy assuming different foreign currency exchange costs, f, in three scenarios: (i) an economy with the natural interest rate lower than the base currency interest rate ($\bar{r} < r_w$), (ii) a natural interest rate higher than the base currency interest rate ($\bar{r} < r_w$), and (iii) ($\bar{r} = r_w$). It appears that the effects of a change in foreign currency exchange fee, f, depend largely on the relative interest rates of the domestic and base currency economies. In case the base currency interbank interest rate r_w is equal to the natural interbank interest rate $\bar{r}$ of the currency board, changing the interest rate channel bounds has no effect on the economy.

Figure 5 shows a model economy with $\bar{r} = r_w$. As the foreign currency exchange costs (measured on the horizontal axes) diminish, the band of possible interbank interest rate fluctuations (denoted by the dashed lines with constant slope) decreases. If f is high enough, domestic interbank market rates are not bounded by the bounds and banks never utilize the foreign currency window at the central bank. As f goes down and the fluctuation band diminishes, banks in some states of the world find it optimal to utilize the foreign currency window. In such states equilibrium interest rates (denoted by solid lines) hit the bounds of $r_w \pm f$. Due to the risk averseness of the banks, the upper bound starts binding sooner than the lower one. As shown in the Appendix Figure 8, this asymmetry vanishes if we set $\rho = 0$.

(a) Interbank market interest rate: state dependent equilibrium interest rates within the channel system

(b) Capital accumulation: individual bank investment levels (firm 1 and firm 2) and aggregate investment
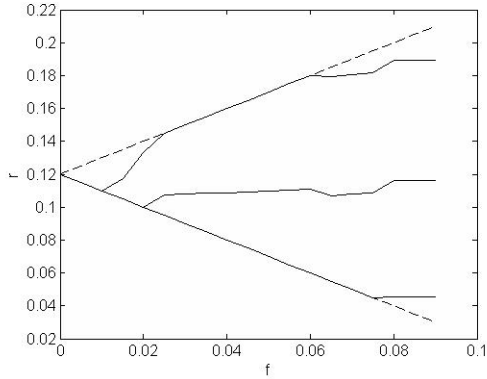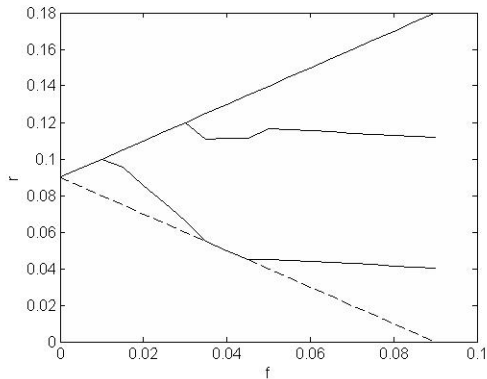
Figure 5: Currency board with $\bar{r} = r_w = 10.7\%$

Since productivity of the next period can take two different values for both of the firms, there are four states of the world. Due to symmetry of the problem, (z_1^g, z_1^b) and (z_1^b, z_1^g) lead to the same equilibrium interbank market interest rate. Thus, if both firms experience a positive productivity shock, the higher income induces a higher demand for the "other" goods, creating a positive liquidity demand shock for the banks. In such a case, equilibrium interbank market interest rates increase as shown in Figure 5(a) by the highest solid line. If both sectors of economy are hit with adverse productivity shocks, there is excess liquidity in the interbank market, which leads to lower interest rates (denoted by the lower solid line). If one of the firms receives a positive shock, the interbank market interest rate hovers around the natural interest rate (denoted by the middle solid line).

Due to the simple structure of the productive side of the economy, we capture the effect of the change in foreign exchange fee policy by looking at the equilibrium investment levels. Figure 5(b) shows investment into capital at the first firm (the second firm's investment level is the same), as denoted by the upper curve. The two lower curves denote investment into the first and second firm by bank x (investment levels of bank y are symmetric). Note that in this scenario changes in foreign exchange fee, f, have almost no effect on aggregate or bank investment levels.

Next, we investigate a scenario where the natural interest rate is not equal to the base currency interest rate. We find that if equilibrium interest rates in a currency board interbank market fluctuate around a level that is different from the base currency interest rate ($\bar{r} > r_w$ or $\bar{r} < r_w$), changes in foreign currency exchange costs have a prominent effect on the economy.

Figure 6 shows a model economy in which the base currency interest rate is higher than the natural interbank market interest rate. As seen in the Figure 6(a), as the foreign currency exchange cost diminishes, the variability of the interbank market interest rate goes down. But at the same time,

(a) Interbank market interest rate: state dependent equilibrium interest rates within the channel system
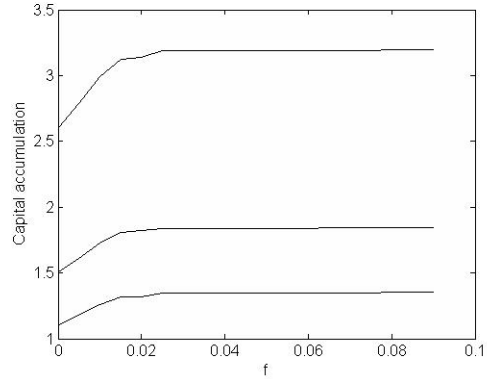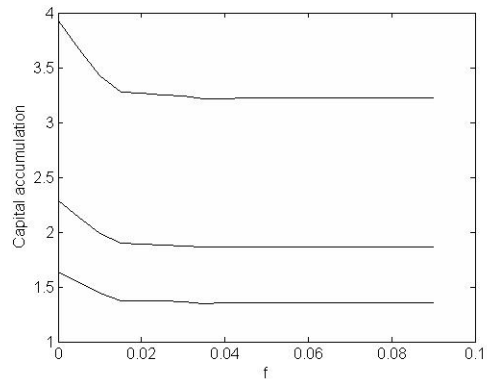

(b) Capital accumulation: individual bank investment levels (firm 1 and firm 2) and aggregate investment

Figure 6: Currency board with $\bar{r} = 10.7\%$, $r_w = 12\%$

(a) Interbank market interest rate: state dependent equilibrium interest rates within the channel system

(b) Capital accumulation: individual bank investment levels (firm 1 and firm 2) and aggregate investment

Figure 7: Currency board with $\bar{r} = 10.7\%$, $r_w = 9\%$

changing interest rate channel bounds has an effect of changing the average equilibrium interest rate. As bounds get tighter, the average equilibrium interest rate increases. In an extreme case of zero foreign currency exchange costs, domestic market interest rates equalize with the foreign interbank market interest rate. As average interest rates go up, investment levels as shown in Figure 6(b) go down. Intuitively, as the cost of borrowing in the interbank market goes up, banks decide to hold more reserves, cutting investment levels.

Figure 7 shows a model economy in which the base currency interest rate is lower than the natural interbank market interest rate. As seen in Figure 7(a), if equilibrium interest rates in a currency board interbank market are, on average, higher than the base currency interest rates ($\bar{r} > r_w$), then decreasing the interest rate fluctuation band effectively decreases the average interest rate. As the

expected interbank interest rates go down, banks choose to hold less in reserves leading to higher investment into capital (Figure 7(b)).

Usually it is argued that a central bank operating under a currency board has very limited – or even no – monetary policy tools available. As our model shows, under certain conditions, there is a channel through which a central bank under a currency board can affect the effective interest rate in the economy. Since central banks under the currency board do not have the usual monetary tools of an independent central bank, this may prove to be an important addition to their limited policy choices.

To give an example, as reported by Jurgilas (2005), domestic interbank interest rates in Lithuania on average were below the euro interbank interest rate. Thus, a decrease of the foreign currency exchange fee by the Bank of Lithuania can be viewed as tightening the monetary policy stance, which, in the presence of "too high" inflation, seems to be a reasonable change in policy.

If domestic market interest rates on average are about the same as the base currency interest rate, our model does not show any effects of a change in the foreign currency exchange fee. Decreasing the fee will trigger more banks to utilize the currency exchange window of the central bank, creating an extra burden to the central bank without any foreseeable benefit. It may be the case that in the presence of some market frictions, as shown by Berentsen and Monnet (2007), changing the width of the channel interest rate policy is equivalent to altering the interest rate policy.

Differences in firm risk profile

Using the model developed we investigate a possibility that, as the variability of the interbank market interest rates changes, there will be a change of the risk profile of investment portfolios. Our expectation is that as the liquidity management costs go down (decrease in the foreign currency exchange fee) banks will choose to have riskier investment portfolios. We simulate an economy assuming $s_h^x = 1.05$, and $s_h^y = 1.1$, making the productivity shock of the 2nd firm more volatile. As seen in Figure 8, changes in f have no effect on the share of investment into "riskier" and "safer" firms. The first firm, which has less uncertainty regarding the productivity shock, receives a bigger share of investment, but that share does not change with f. Thus, our model does not suggest that variability of interbank market interest rates has an effect on bank investment portfolio choices.

4.4   Robustness

We varied all parameters reported in Table 1 in order to verify the robustness of the results presented. None of the qualitative results change. Increasing or decreasing the average productivity parameter A affects the natural rate of interest $\bar{r}$ (as shown in Figures 9 through 11 in the Appendix B). Still, the same argumentation applies: if the base currency interest rate r_w is below the natural interest
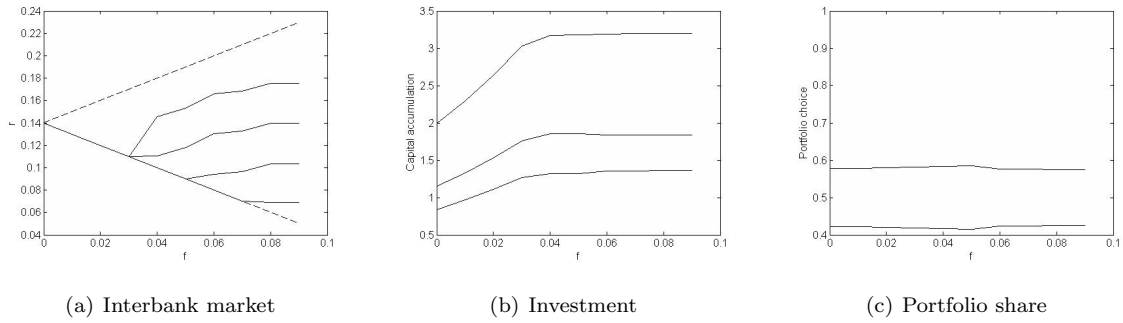
(a) Interbank market	(b) Investment	(c) Portfolio share

Figure 8: $(\bar{r} = 11.2\%, \ r_w = 14\%, \ s_h^x = 1.05, \ s_h^y = 1.1)$

rate, tightening the bounds is equivalent to easing the monetary policy.

The results are robust to changes in risk averseness (Figures 12 through 14), preference for credit goods (Figures 15 and 16), or elasticity of demand for excess reserves (Figure 17). A decrease in the risk averseness parameter, ρ, a decrease in depreciation, δ, and an increase in share of capital in production, α, all increase the natural interest rate of the economy.

5   Conclusions

In this paper we provide a framework under which we can analyze the effects of monetary policy in a currency board country. In such an environment the usual monetary policy tools cannot be implemented. Using the general equilibrium model developed, we show that there exists an instrument that central banks may consider using in order to pursue active monetary policy by changing the effective interest rate in the interbank market. Foreign currency exchange costs that banks incur exchanging base currency at the central bank can prove to be an effective monetary policy tool. We show that, under certain conditions (if the natural interest rate of the domestic interbank market differs from the base currency interest rate), changes in these costs affect the real side of economy. Since central banks under the currency board do not have the usual monetary tools of an independent central bank, this may prove to be an important addition to their limited policy choices.

Berentsen and Monnet (2007) argue that changing interest rate channel bounds can have the effects of a change in monetary policy stance. We report a similar effect, although arising due to a different mechanism and in an environment where the usual monetary policy tools do not work. Low implementation costs, high effectiveness due to no policy lag, and having limited alternatives makes this an attractive monetary policy tool for central banks operating under the currency board regime.

Within the framework of the model developed, there appears to be no effect of a change in

foreign currency costs towards the risk profile of investment projects undertaken. We do, however, acknowledge that there might be some frictions in the market not accounted for by the model that may make the investment portfolio risk profile respond to the uncertainty in the interest rates. Other interesting extensions of the model would be to assume infinitely lived agents and to introduce a required reserves constraint into the bank problem. We leave that for future research.

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Appendix

A   Infinite horizon formulation

In this section we provide the formulation of the model assuming that agents are infinitely lived $(T = \infty)$.

B   Firms

Each of the two firms produce one product only. Both firms are assumed to have the same production technology with constant returns to scale:

$$Y_i = A^{z_i} K_i^{\alpha}, \ \ i = \{1, 2\}$$

Labor is normalized to 1. K_i denotes capital of the firm i, A is average productivity, and z_i is the productivity shock. Note that we assume that goods from different sectors of economy are equally productive when used as capital. The productivity shocks, z_i, of each period are assumed to be i.i.d. lognormal, with mean μ and variance-covariance matrix Σ. Both firms pay the marginal product for factors of production according to the realization of the productivity shock. Thus firms operate under zero economic profit condition, regardless of the state of economy, given by:

$$rl_i = MP_k(z_i, K_i)$$
$$w_i = MP_l(z_i, K_i)$$
$$K_i = k_{xi} + k_{yi}$$

where $i = \{1, 2\}$, K_i denotes the capital level accumulated in firm i, and k_{xi}, k_{yi} denote, respectively, bank x and y's capital holdings in firm i.

C   Households

The two types of households solve a symmetric problem. Given the current state of the economy, and taking the strategies of the banks and the aggregate behavior of both types of households as given, each individual household type $i = \{a, b\}$ decides on the consumption of "apples" and "bananas" (c_{ia}, c_{ib}) and the allocation of savings (deposits, d_i, and bonds, b_i). Thus the problem solved by household a is (with prime variables denoting next period values) as follows:

$$V_a(z, db, B, H, h_a) = \max_{dh_a} \left[U(dh_a) + \beta \underset{z'}{E} V(z', db', B', H', h'_a | z, db) \right] \tag{11}$$

s.t.

$$c_{aa} + c_{ab}e(DH)(rd_x - rf_x) + s_a = d_a rd_x + w_a(z_1, k_{x1}, k_{y1}) + b_a \cdot tr \tag{12a}$$

$$c_{ab}e(DH) \leq d_a \tag{12b}$$

$$z' = \epsilon', \text{ and } \epsilon \overset{iid}{\sim} LN(0, \Sigma) \tag{12c}$$

$$DH_a = DH_a(z, db, B, H) \tag{12d}$$

$$DH_b = DH_b(z, db, B, H) \tag{12e}$$

$$\{d'_a, b'_a\} = \{s_a \psi_a, s_a(1 - \psi_a)\} \tag{12f}$$

$$\{D'_a, B'_a\} = \{S_a \Psi_a, S_a(1 - \Psi_a)\} \tag{12g}$$

$$\{D'_b, B'_b\} = \{S_b \Psi_b, S_b(1 - \Psi_b)\} \tag{12h}$$

$$B' = B'(z, db, B, H) \tag{12i}$$

$$\{db_x, db_y\} = db(z, B, H) \tag{12j}$$

$$\{db'_x, db'_y\} = (z, db, B, H) \tag{12k}$$

Furthermore:

$$z = \{z_1, z_2\}$$

$$B = \{rd_x, rd_y, rz_x, rz_y, k_{x1}, k_{x2}, k_{y1}, k_{y2}\}$$

$$H = \{D_a, B_a, D_b, B_b\}$$

$$\{db_x; db_y\} = \{rd'_x, I_{x1}, I_{x2}; rd'_y, I_{y1}, I_{y2}\}$$

$$h_a = \{d_a, b_a\}$$

$$dh_a = \{c_{aa}, c_{ab}, s_a, \psi_a\}$$

$$DH_a = \{C_{aa}, C_{ab}, S_a, \Psi_a\}$$

and (z_1, z_2) are productivity shocks in respective sectors of economy. h_a is the state variable of a representative household a, while B and H are aggregate state variables for banks and households respectively. db denotes optimal policy response of the banking system, given the current state of the economy. dh_a denotes optimal policy response of a representative household a, while DH_a denotes the aggregate optimal policy response of type a households.

As goods are traded for goods, we normalize the price of the good produced in sector a to one, so that ϵ represents the relative price of "bananas" in terms of "apples." The relative price is determined in the goods market, $c_{ab}\epsilon = c_{ba}$, assuming zero net flow of goods from one sector to the other in each period.

Household a decides on present period consumption of the good it produces by itself, c_{aa}, the good produced by the other sector c_{ab}, savings s_a, and the proportion of savings deposited at the

bank, ψ_a, and invested in bonds, $(1 - \psi_a)$. Equation (12a) represents the budget constraint faced by the household. The household collects interest rd_x on the deposits held to maturity $(d_a - c_{ab}\epsilon)$. If a deposit contract is terminated before maturity, the household receives only a fraction of the agreed interest rate, rf_x. For simplicity we assume that the deposit rate and fractional deposit rate are linearly related: $rf_x = fr \cdot rd_x$, with $0 \leq fr \leq 1$. The household also collects interest rate, tr, paid on government bond holdings b_a.

Furthermore, we make the assumption that goods produced in the same sector where a household is working can be purchased on credit, while the good produced in the other sector can only be purchased with the goods stored at the bank. The rationale is that the producer of the other sector does not trust a household with which the producer has no relationship, while the employer of the household has an outstanding liability to that household (i.e., wage payment) and thus is willing to sell goods on credit. In this context, Equation (12b) denotes a "goods in advance" constraint faced by the household a. Thus, apart from the interest income, households have an incentive to hold deposits in expectation of the future consumption of goods produced in the other sector.

A household solves its problem taking the aggregate optimal policy response of households (Equations (12d)–(12e)) and the optimal policy of the banks (Equations (12j)–(12k)) as given. The solution of this problem is household a's response function $dh_a(z, db, B, H, h_a)$. In equilibrium, decisions of representative household a must be compatible with the aggregate decision of type a households:

$$DH_a(z, db, B, H) = dh_a(z, db, B, H, H)$$

D Banks

There are two banks indexed $j = \{x, y\}$ that act strategically in making decisions. Each bank takes optimal household response functions $(DH_i(z, ng, B, H), i = \{a, b\})$, and the optimal policy of the other bank into consideration when solving its problem. The problem solved by bank x is[4]

$$V_x(z, B, H, db_y) = \max_{db_x} \Pi(z, B, H, DH_a(z, db, B, H), db_x | db_y) \tag{13}$$
$$+\beta \underset{z}{E} V_x(z', db', B', H')$$

s.t.

$$\Pi = rl_1 k_{x1} + rl_2 k_{x2} - rd_x(D_a - C_{ab}\epsilon) - rf_a C_{ab}\epsilon \tag{14a}$$
$$+(rz_x - C_{ab}\epsilon)r - B_a tr$$
$$rz'_x = D'_a - I_{x1} - I_{x2} \tag{14b}$$
$$k'_{xi} = (1 - \delta)k_{xi} + I_{xi}, \text{ and } i = \{1, 2\} \tag{14c}$$

---

[4]Bank y solves a symmetric problem.

Bank x policy choice variables are:

$$db_x = \{rd_x, I_{x1}, I_{x2}\}$$

where rd_x is the deposit rate, I_{x1} is investment into firm 1, and I_{x2} is investment into firm 2. Equation (14a) provides the return of the bank in period t. Each period banks collect interest on capital holdings, (k_{x1}, k_{x2}), and pay interest on deposits held to maturity $(D_a - C_{ab}\epsilon)$ and withdrawn before maturity $(C_{ab}\epsilon)$. If reserves of a bank are insufficient to execute payments initiated by household a $(rz_x - C_{ab}e \leq 0)$, the bank will obtain liquidity on the interbank market paying interest rate r. Finally, the bank must pay a tax, which is collected by the government. The solution to this problem is the bank's policy function $\{rd'_x, I_{x1}, I_{x2}\} = db_x(z, B, H|db_y)$. Note that bank x formulates its optimal policy given the optimal policy of bank y.

E   Equilibrium

The equilibrium in this formulation is defined by (i) household policy functions $dh_i(z, db, B, H, h_a)$, $i = \{a, b\}$, (ii) bank policy functions $db_j(z, B, H|db_{-j})$, $j = \{x, y\}$, and (iii) relative price ϵ and equilibrium interbank interest rate r sequences such that:

- Given optimal bank policy, household policy functions solve the respective representative household's problem as defined in Equation (11).

- Representative household behavior is compatible with the aggregate:

$$DH_i(z, db, B, H) = dh_i(z, db, B, H, H)$$

- Given optimal household policy functions, bank policy functions solve respective bank problems as defined in Equation (13).

- Optimal bank policy functions yield Nash equilibrium in every proper subgame:

$$\{db_x(z, B, H), db_y(z, B, H)\} = NASH\left[db_x(z, B, H|db_y), db_y(z, B, H|db_x)\right]$$

- Goods and interbank markets clear.

Since the two banks act strategically in choosing their policy, equilibrium optimal bank policies are defined by a Markov perfect equilibrium.

F   Proposed solution algorithm

Due to the complex game theoretic structure, this model does not have a closed form solution; therefore, we have to resort to computational methods. Building on the proposed solution techniques

developed by Ambler and Paquet (1997) for a general equilibrium dynamic Stackelberg game, and Nie et al. (2006) in case of dependent followers, we propose the following solution method:

- Guess policy functions of the banks $(db_x(z, B, H|db_y), db_y(z, B, H|db_x))$.

- Find the Markov perfect equilibrium $(db_x(z, B, H), db_y(z, B, H))$ implied by these functions.

- Given $(db_x(z, B, H), db_y(z, B, H))$, guess aggregate household policy (DH_a, DH_b).

- Given bank and aggregate household policy functions, solve the representative household problem.

- If the solution of the representative household problem is not compatible with the aggregate household decisions, update the aggregate household policy (DH_a, DH_b) until convergence.

- Given household response functions $DH_i(z, db, B, H)$, $i = \{a, b\}$, solve bank problems for the optimal policy function.

- If optimal policies differ from the ones assumed, update.

G   Robustness checks

The figures below represent robustness checks. None of the qualitative results change as various parameters are altered.
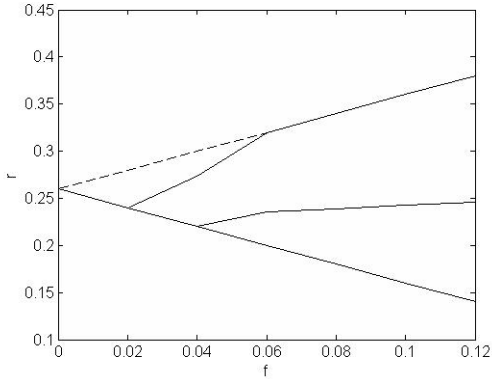
(a) Interbank market interest rate: state dependent equilibrium interest rates within the channel system
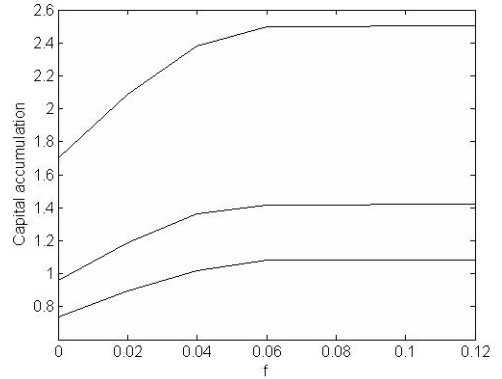
(b) Capital accumulation: individual bank investment levels (firm 1 and firm 2) and aggregate investment

Figure 9: Robustness check: $A = 3$, $r_w = 26\%$
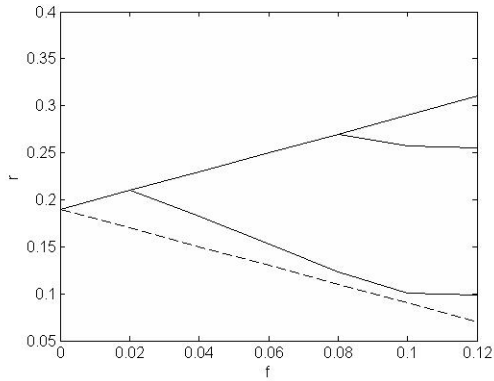
(a) Interbank market interest rate: state dependent
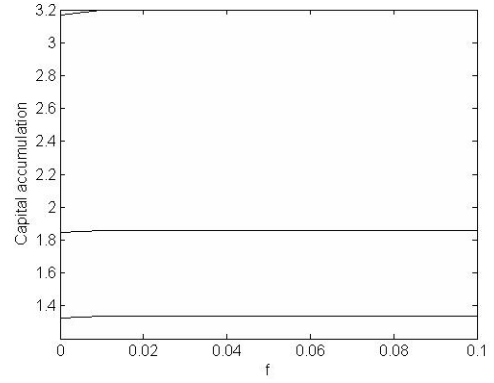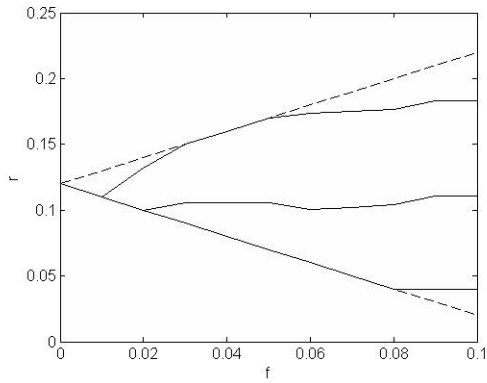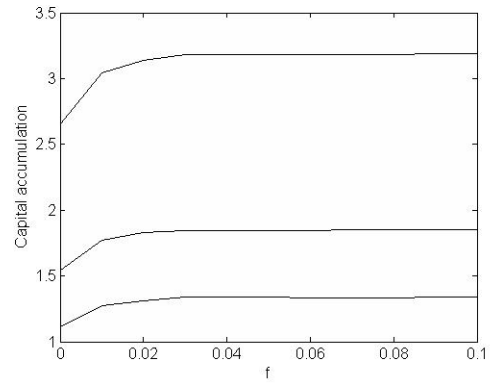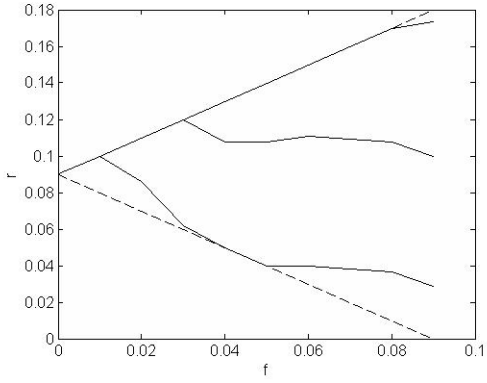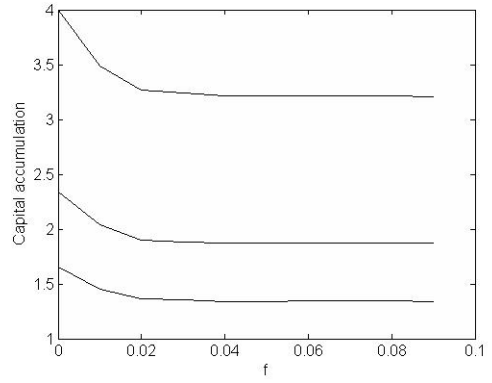equilibrium interest rates within the channel system
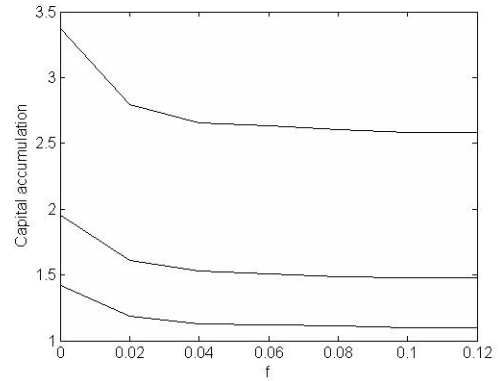
(b) Capital accumulation: individual bank investment
levels (firm 1 and firm 2) and aggregate investment

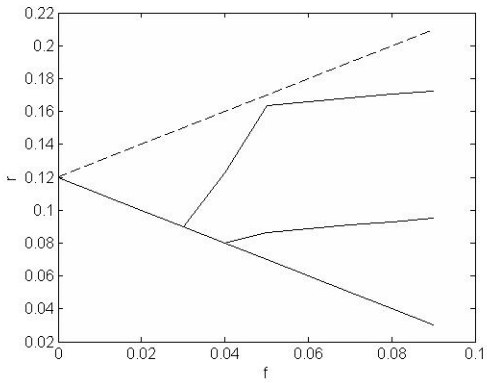Figure 10: Robustness check: $A = 3$, $r_w = 19\%$
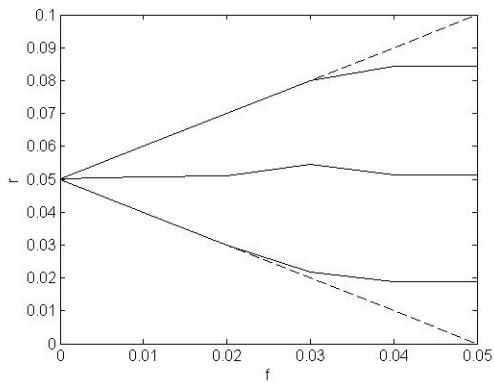
(a) Interbank market interest rate: state dependent
equilibrium interest rates within the channel system
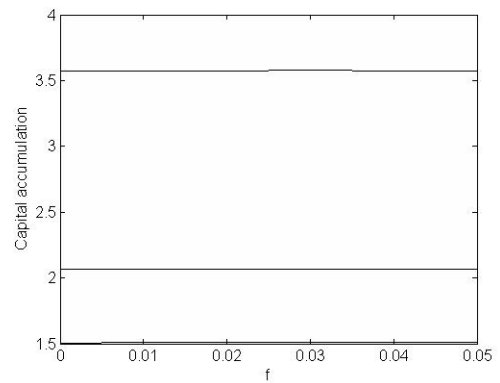
(b) Capital accumulation: individual bank investment
levels (firm 1 and firm 2) and aggregate investment

Figure 11: Robustness check: $A = 1.5$, $r_w = \bar{r} = 5\%$
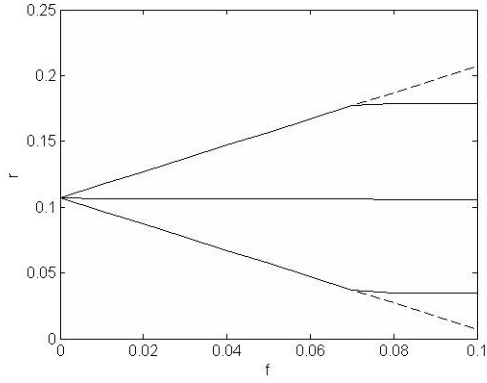
(a) Interbank market interest rate: state dependent
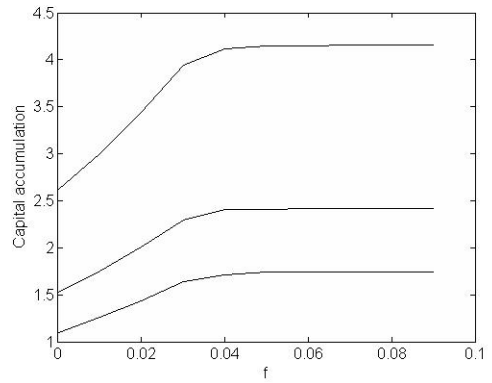equilibrium interest rates within the channel system

(b) Capital accumulation: individual bank investment
levels (firm 1 and firm 2) and aggregate investment

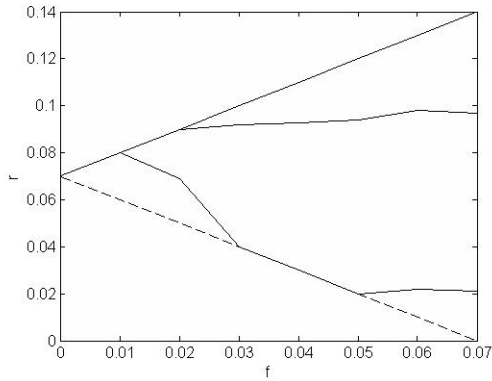Figure 12: Robustness check: $\rho = 0$, $r_w = \bar{r} = 10.7\%$

(a) Interbank market interest rate: state dependent
equilibrium interest rates within the channel system

(b) Capital accumulation: individual bank investment
levels (firm 1 and firm 2) and aggregate investment

Figure 13: Robustness check: $\rho = 0$, $r_w = 12\%$, $\bar{r} = 10.7$

(a) Interbank market interest rate: state dependent
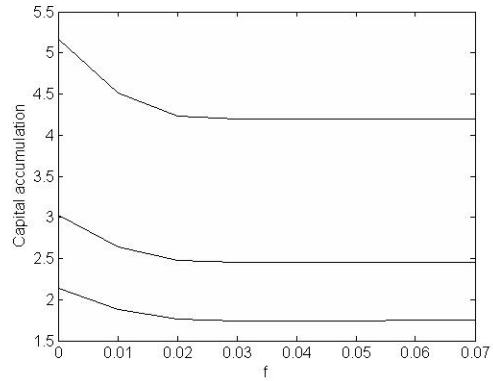equilibrium interest rates within the channel system

(b) Capital accumulation: individual bank investment
levels (firm 1 and firm 2) and aggregate investment

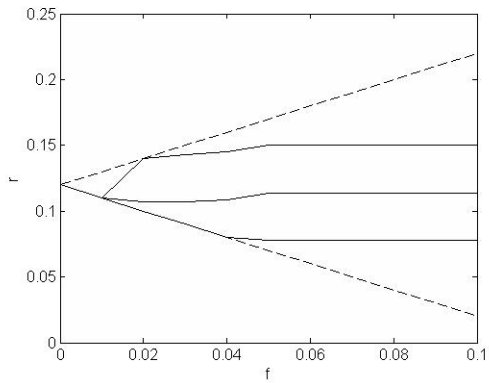Figure 14: Robustness check: $\rho = 0$, $r_w = 9\%$, $\bar{r} = 10.7\%$

(a) Interbank market interest rate: state dependent
equilibrium interest rates within the channel system

(b) Capital accumulation: individual bank investment
levels (firm 1 and firm 2) and aggregate investment

Figure 15: Robustness check: $g = 0.6$, $r_w = 12\%$, $\bar{r} = 9.8\%$

(a) Interbank market interest rate: state dependent
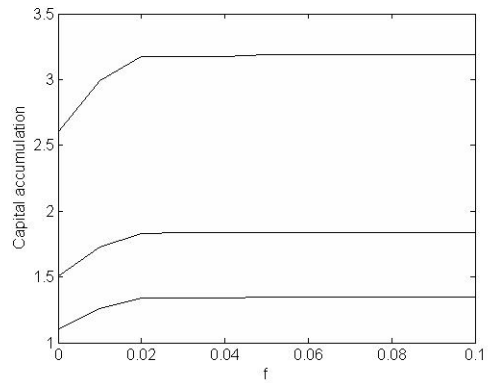equilibrium interest rates within the channel system

(b) Capital accumulation: individual bank investment
levels (firm 1 and firm 2) and aggregate investment

Figure 16: Robustness check: $g = 0.6$, $r_w = 7\%$, $\bar{r} = 9.8\%$

(a) Interbank market interest rate: state dependent
equilibrium interest rates within the channel system

(b) Capital accumulation: individual bank investment
levels (firm 1 and firm 2) and aggregate investment

Figure 17: Robustness check: $\phi = 0.2$