Reserve Accumulation and Bank Lending: Evidence from Korea*

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Abstract

Reserve accumulation is funded by the central bank's domestic borrowing as it always sterilizes reserve purchases by increasing domestic liabilities. The central bank borrowing could crowd out firms' borrowing under imperfect international capital mobility. I present a model that illustrates the mechanism and examine monthly balance sheets of Korean banks from September 2003 to August 2008 to find that bank lending to firms did decline after reserve accumulation. Controlling for individual effects and time effects, it is estimated that bank lending declined by 50 cents after one additional dollar of reserve accumulation. A causal relationship is verified by differences-in-differences identification. After one standard deviation reserve accumulation shock, primary dealer banks and foreign bank branches cut lending growth by 0.4 and 1.6 percentage points more than non-primary dealer banks and domestic banks, respectively.

JEL Classification: E22, E58, F31

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1 Introduction

International reserve management is a popular policy instrument among open economies. In many countries, it is the main tool to cope with volatile capital flows. Following the capital account liberalization of the early 1990s, many countries experienced sudden stops later in the same decade. They began accumulating considerable amounts of foreign exchange reserves from the early 2000s. Some other countries have resorted to reserve accumulation to back their export-led growth models. Reserve accumulation is thought to be the second-best policy after direct export subsidies which are banned by international trade agreements. Figure 1 compares the reserve-to-GDP ratio of 1996 with that of 2016. Most countries are located to the right of the 45-degree line. The reserve-to-GDP ratio increased significantly in most economies over the last 20 years.

Figure 1 here.

This paper examines the effects of reserve accumulation on bank lending. Despite the popularity of reserve policy, the existing literature on foreign exchange reserves is concentrated mainly on the motivations and benefits of reserve hoarding, while domestic consequences are given little attention. Discussions on the cost of reserve accumulation are mostly focused on the carry cost, which is estimated by comparing the return on reserve assets and the cost of corresponding liabilities. What happens in the domestic financial market in the process of central bank operations for reserve accumulation has been largely ignored. By investigating how reserve accumulation affects domestic credit allocation, this paper aims to fill in this gap in the literature.

Conceptually, reserve accumulation is the same as foreign saving funded by central banks' domestic borrowing. It has been documented in the literature that heavy reserve accumulator countries have sterilized most of their reserve purchases. See Lavigne (2008), Reinhart and Reinhart (2008), Aizenman and Glick (2009) or Mehrotra (2012). Central banks have also

declared that they absorb excessive liquidity after FX purchases.[1] To nullify the effect of reserve purchases on target interest rates, the central bank has to reduce its net domestic assets. Whether the sterilization is done through issuance of central banks' own securities, transfers from government, or raising reserve requirements, it amounts to central banks' borrowing from the domestic financial sector. The proceeds of this borrowing are exchanged with foreign currency in the local FX market and invested abroad in mostly safe assets.

Reserves were accumulated on a large scale, often dozens of percent of GDP, in many countries. The flip side of it is that central banks borrowed heavily from the domestic financial sector. Central banks' large scale borrowing could have serious implications in local financial markets influencing credit allocation and altering financial intermediaries' behavior in distortionary ways.[2] In this paper, I focus on banks' loan provision to private firms.

This paper shows that reserve accumulation reduces bank loans to firms. As central banks fund reserve purchases by borrowing from the domestic financial sector, banks are left with less funds. If domestic assets are imperfect substitutes for foreign assets such that the banks cannot borrow from abroad the same amount they lend to the central bank, banks would need to reduce loans to firms. I describe this by developing a two-period small open economy model, and provide micro evidence from Korean banks' monthly balance sheets from September 2003 to August 2008.

The analytical model describes the mechanism of bank loan crowding-out by reserve accumulation. Unlike other existing models of reserves, my model describes reserves being funded by a central bank's domestic borrowing, and include other private borrowers that compete with the central bank in a loanable fund market. As a response to the central

[1]For example, the Bank of Korea states in the 2004 annual report(The Bank of Korea, 2004) that "During the year, the Bank of Korea had no option but to absorb the excess liquidity supplied through the foreign sector owing to the widened current account surplus by means of the issue of Monetary Stabilization Bonds (MSBs) in order to maintain the call rate at its target level."

[2]For instance, banks may opt to increase the riskiness of their portfolio to offset the effect of low yield sterilization assets that they are forced to hold. See Yu (2014) for a similar argument regarding Chinese reserve accumulation, and Kumhof and Tanner (2005) for discussion on the effect of government debt on bank portfolios.

bank borrowing, the local financial market tries to borrow more from abroad. However, the international financial intermediation is subject to a limited liability constraint and the private sector can only partially offset the public outflows, so Ricardian equivalence fails. Consequently, bank loans are crowded out, and this negatively affects investment and capital accumulation.

This paper provides bank level evidence for the crowding-out effect of reserve accumulation. I investigate monthly balance sheets of all banks in Korea over the massive reserve accumulation period (September 2003 to August 2008). First, controlling for individual bank effects and year-by-quarter effects, I find that the bank loan growth rate declined significantly after reserve accumulation. The crowding-out coefficient, defined as the ratio of reduced lending to accumulated reserves, is estimated to be 0.5. Second, I identify causation using a differences-in-differences framework. Specifically, I compare primary dealer banks with non-primary dealers, and foreign bank branches with domestic banks. The impact of sterilized reserve accumulation starts from the primary market of sterilization security. The central bank securities will be bought by primary dealer banks first, before they are circulated in the secondary market later. Hence, primary market participant banks would reduce lending more than non-participants. Furthermore, primary dealer banks have incentives to cooperate with the central bank on sterilization for renewal of their status as primary dealers. As they take over the central bank securities, they become less able to increase loans. Foreign bank branches are well known for their pursuit of risk-free public securities. The main business of the branches is not in making loans but in trading safe securities, and they are willing to slow down their lending growth when more profitable sterilization securities are supplied. I provide evidences that support these conjecture.

The remainder of this paper is organized as follows. Section 2 overviews the related literature and documents the contributions of this paper. Section 3 provides the analytical model that describes the domestic consequences of reserve accumulation, including the reduction in bank loans. Section 4 explains the empirical framework and Section 5 shows the results.

Finally, Section 6 concludes.

2 Related Literature

Reserve accumulation came into the focus of research interest in the mid 2000s as international reserve hoarding became distinct. Many theoretical models are written to uncover the motivation and benefits of reserve accumulation. Most of the existing reserve accumulation models, however, describe reserves as being accumulated by lump-sum taxation or by a representative agent's voluntary saving. Examples include Caballero and Panageas (2005), Durdu et al. (2009), Alfaro and Kanczuk (2009), Jeanne and Ranciere (2011), Jeanne (2012), Benigno and Fornaro (2012), and Bacchetta et al. (2013). Reserve accumulation has limited effects on the supply and demand of funds in these models as the reserve accumulation is not central bank's borrowing. There are some FX intervention models that describe intervention as being executed by central bank's borrowing. They, however, do not have competing private borrowers. See Gabaix and Maggiori (2015) or Amador et al. (2016). By construction, they fail to observe the effect of reserve accumulation on other borrowers in the economy. I develop a reserve accumulation model which has private borrowers and reserves are accumulated by central bank's borrowing. Using the model, I show analytically that bank loans are crowded out after reserve accumulation. Bank loans are directly related to the investment and capital, so it brings real effects.

This paper adds to the literature on the cost of reserves. This literature is mainly focused on direct sterilization costs or the carry cost of reserves. They estimate the spread of sterilization bonds over reserve assets. Examples are Calvo (1991), Calvo et al. (2012), Rodrik (2006), Lavigne (2008), Yeyati (2008) and Adler and Mano (2016). Calvo (1991) investigates this cost and warns of the "perils" of sterilized intervention. Calvo et al. (2012) also weigh the cost of reserves using this measure. Rodrik (2006) suggests a similar but different definition of reserve cost. He argues that the "social cost" of reserves should be

calculated from the spread between the yield on reserves and the cost of foreign borrowing, since reserves could have been used to reduce the country's external debts. Yeyati (2008) adds to the discussion by arguing that we should also consider the effect of reserve on credit risk and soverign spread. Abundant reserves lower external borrowing costs and it should be counted when one estimates costs of reserves.

There are several empirical studies documenting the possibility of reserves negatively affecting investment and growth. Reinhart et al. (2016) relate the decline of growth in Asia after 2000 with reserve accumulation and bring up the possibility that private sector investments have been crowded out by reserve accumulation. Their argument is supported by correlations of macro aggregates and VAR evidence. In a similar vein, Lee and Choi (2010) assert that reserve accumulation tend to reduce domestic investment. They find strong negative correlation between investment rate and reserve to GDP ratio from panel analysis of 20 Asian countries over 1980-2008. A couple of studies investigate micro level evidence focusing on bank lending. Cook and Yetman (2012) compare 2003 and 2007 balance sheets of 55 banks in Asia and find that one percentage point increase in reserves is associated with a 1.3% decline in loan growth. Kuttner and Yetman (2016) use panel data of Asian banks to find that sterilization through reserve requirement hikes retards bank lending growth. My paper contributes to the literature on cost of reserves by documenting the negative effect of reserve accumulation on bank lending. Unlike existing studies, I use detailed bank panel data of one country and exploit bank heterogeneity to identify causation.

This paper is also related to the burgeoning literature on bank lending behavior. Bank lending has been an important interest of many researchers since it can affect resource allocation, productivity and growth. Many factors that can affect bank lending have been examined by the literature. Buch and Goldberg (2014) study how liquidity risk affects bank lending in different countries. Baskaya et al. (2017) show that capital inflows lead to bank loan expansion in Turkey. Jiménez et al. (2014) find that expansionary monetary policy induces lowly capitalized banks to provide more loans to risky firms. Rodnyansky

and Darmouni (2017) find effects of U.S. quantitative easing on bank lending. Ivashina and Scharfstein (2010) identify banks which cut lending more than others during the Great Recession, exploiting cross-sectional differences in bank characteristics. The contribution of my work to this literature is that I investigate a previously unstudied shock, reserve accumulation with a new dataset from Korea.

3 Mechanism

I study a two period ($t = 1, 2$) small open economy model. The economy is inhabited by households, firms and banks, each with a unit measure. There is a central bank which accumulates foreign exchange reserves. In general, the need for FX reserves would arise from precaution against sudden stops, or from the desire of achieving a trade surplus. I do not provide a particular justification in this paper, although the model shows trade balance improvement through reserve accumulation. Instead, I take central bank intervention as given and focus on its effects on bank loans, firm and production. In addition, there is a continuum of FX intermediaries channelling international capital flows. Figure 2 shows the flows of funds among agents which will be discussed below.

Figure 2 here.

3.1 Households

A continuum of identical households consume two goods, home goods and foreign goods. Home goods are the numeraire in this economy, and are produced by domestic firms, while foreign goods are the numeraire outside this economy, and are imported. I use the word

currency to mean a claim to the numeraire of the economy hereafter. The exchange rate e_t is defined as the price of a unit of foreign good in units of home goods at time t. An increase in e_t is therefore depreciation as usual. The households' problem is:

$$\begin{aligned} \max \quad & \ln C_1 + \beta \ln C_2 \\ s.t. \quad & C_t \equiv C_{H,t}^{\chi} C_{F,t}^{1-\chi} \\ & C_{H,1} + e_1 C_{F,1} = \pi_{B,1} \qquad (1) \\ & C_{H,2} + e_2 C_{F,2} = \pi_{B,2} + \pi_F - \tau \qquad (2) \end{aligned}$$

χ governs the household preference over home goods and foreign goods, and is between zero and one. Households own banks and firms and earn profits $\pi_{B,t}, \pi_F$, respectively. τ is a tax levied by the central bank, which will be explained later.

The households' problem is stylized as I strive to focus on transactions between banks and firms. The households do not participate in the domestic financial market directly. Instead, they smooth consumption through their ownership of banks.[3] The only decision of the households is on the consumption ratio between home goods and foreign goods, which satisfies

$$\frac{\chi}{C_{H,t}} = \frac{1-\chi}{e_t C_{F,t}} = \lambda_t \qquad (3)$$

In the optimum, the marginal utility per one unit of domestic currency spending is the same in both home good and foreign good consumption, and equals λ_t.

To clear the home goods market, I need to introduce a demand curve of the rest of the world (RoW). From Equation (3), we see that the households devote a fraction $(1-\chi)$ of total expenditure E_t to foreign goods ($e_t C_{F,t} = (1-\chi)E_t$). By symmetry, I assume that RoW spends $(1-\chi)$ portion of its total expenditure E_t^* on home goods.

$$\frac{1}{e_t} C_{H,t}^* = (1-\chi) E_t^*$$

[3]This feature is also present in Benigno and Fornaro (2012).

By normalizing $E_t^* = (1-\chi)^{-1}$, I make foreign demand for home goods the same as the exchange rate.

$$C_{H,t}^* = e_t \tag{4}$$

3.2 Firms

The firms operate with a CRS technology where capital is the only input. z is the productivity.

$$Y_t = zK_t$$

A representative firm enters the first period with initial capital K_1 and existing debt L_1 owed to the banks. It is assumed that the initial debt is same as the first period output ($L_1 = zK_1$), so the firm produces with initial capital and uses the entire output to pay back the initial debt. The firm can get loan L_2 from the banks and uses it to invest in K_2. Capital does not depreciate. Investment is done using home goods and is irreversible.[4] The firm yields profit to the households only in the terminal period. Consequently, the firms' problem is as follows:

$$\max \quad \pi_F = zK_2 - RL_2 \tag{5}$$

$$s.t. \quad K_2 = K_1 + L_2 \tag{6}$$

The borrowing rate in this economy is R and the capital rate of return is z. The solution to firms' problem shows that R and z should be equal to each other in any equilibrium.

$$R = z \tag{7}$$

[4]If investment is done by foreign goods (or more generally, some combination of foreign goods and home goods), reserve accumulation will crowd out bank loans even more because it will make investment more expensive. I close this channel by assuming investment is done only using home goods, and focus on the crowding out of loans due to imperfect international capital flows.

For simplicity and analytical results, I further assume here the following.

$$\beta z = 1$$

Therefore, the capital rate of return z is β^{-1}. This assumption is harmless for the purpose of this model, because household consumption smoothing is not the focus.

3.3 Banks

A representative bank yields profit to the households in both periods. Essentially, it does consumption smoothing on behalf of the households. The bank has initial fund L_1 and it can also issue bonds to the FX intermediaries. The bank's problem is:

$$\begin{aligned} \max \quad & \pi_{B,1} + \beta \frac{\lambda_2}{\lambda_1} \pi_{B,2} \\ s.t. \quad & L_1 + B = \pi_{B,1} + L_2 + S \qquad (8) \\ & RL_2 + RS = \pi_{B,2} + RB \qquad (9) \end{aligned}$$

λ_t is the households' marginal utility at time t. B is banks' bond issuance which will be bought by FX intermediaries, and S is lending to the central bank. In the absence of risk, all domestic liabilities are perfectly substitutable. Hence, all domestic bonds in this model bear the same interest rate R. The banks' first order condition is a typical Euler equation.

$$\lambda_1 = \beta R \lambda_2 \qquad (10)$$

3.4 FX intermediaries

There is a growing literature on segmented international financial markets in which foreign demand for home bonds is finitely elastic.[5] I follow this literature to bring uncovered interest rate parity(UIP) failure into the model.

There is a continuum of FX intermediaries. They start with no capital of their own and trade bonds. They borrow q/e_1 from the foreign financial market in foreign currency at world interest rate R^* and exchange it with domestic currency in the SOE's FX market.[6] Then they lend q to domestic banks at rate R. Hence the value of the FX intermediary in terms of home currency as of period 2 is:

$$V = \left(R - R^* \frac{e_2}{e_1} \right) q = \Omega q \tag{11}$$

Ω is the rate of return on the FX intermediary's FX intermediation q.

After taking positions, the FX intermediary can divert a portion $\Gamma|\frac{q}{e_1}|$ of the funds it intermediates.[7] If the FX intermediary diverts the funds, it would get the proceeds from diversion in period 2, and the lenders to the FX intermediary recover a portion $1 - \Gamma|\frac{q}{e_1}|$ of their credit position $|\frac{q}{e_1}|$. Since lenders correctly anticipate the investors' incentives for diversion, the FX intermediaries are subject to a credit constraint of the form:

$$\frac{V}{e_1} \geq \Gamma \left| \frac{q}{e_1} \right| \cdot \left| \frac{q}{e_1} \right| \tag{12}$$

Since the value of the firm is linear in q, while the constraint is convex in q, the constraint always binds. Substituting the value into the constraint, and aggregating across the unit

[5] For example, see Gabaix and Maggiori (2015), Fanelli and Straub (2016), and Amador et al. (2016).

[6] It is assumed that the exogenous world interest rate R^* is smaller than the rate of return z of this economy as we are analyzing private capital inflows.

[7] Hence, $\Gamma|\frac{q}{e_1}|$ is a proportion. Combining the FX intermediaries' value and constraints, $\Gamma|\frac{q}{e_1}| = \frac{V}{q} = \Omega$. $\Gamma|\frac{q}{e_1}| < 1$ is always satisfied in an equilibrium if one makes a mild assumption that the return rate of FX intermediation is less than 100%. $(-1 < \Omega < 1)$

mass of FX intermediaries, the capital inflow from abroad Q is derived as:

$$Q = \frac{1}{\Gamma}\left(Re_1 - R^* e_2\right) \tag{13}$$

In foreign currency terms, the capital flow to this economy in period 1 is

$$\frac{Q}{e_1} = \frac{1}{\Gamma}\left(R - R^* \frac{e_2}{e_1}\right)$$

In these expressions, the term in parenthesis is the deviation from the uncovered interest rate parity condition. So the capital flow is linear in the deviation from UIP and Γ is the parameter that governs the degree of openness of this economy. If Γ is zero then international capital flows are frictionless and UIP holds. When Γ goes to infinity, then there are no capital flows and the economy is in financial autarky. In what follows, Γ is assumed to be a positive number and UIP fails in the model economy.[8]

3.5 Central Bank

For reasons exogenous to the model, the central bank sets a target for foreign exchange reserves of F measured in units of foreign currency. It cannot borrow from foreigners ($F \geq 0$), and the reserve accumulation cannot exceed total exports which are equal to one in terms of foreign currency($F \leq 1$).[9] It borrows S from the domestic financial market, converts this to foreign currency in the FX market and invests abroad.

For the sake of completeness, the central bank brings the return on reserves back to

[8]In the absence of uncertainty, expected return is the same as realized return in this model. Hence, UIP violation also means CIP violation. In the data, UIP does not hold but CIP does. This is problematic to the literature of segmented international markets. As it is pointed out by Amador et al. (2016), however, segmented market models predict that the CIP gap increases with reserve accumulation, which is consistent with the data.

[9]Reserves not exceeding total exports is a mild assumption. For instance, in the year 2007, the Korean exports of goods were 382 billion USD while reserves outstanding at the end of the same year were 262 billion USD.

the home country and pays back the domestic debt in period 2. Through this operation the central bank may occur fiscal losses. It covers the loss by lump-sum taxation on the households. The central bank budget constraints in each period are:

$$S = e_1 F \tag{14}$$

$$R^* e_2 F + \tau = RS \tag{15}$$

Equation (15) determines the amount of tax τ needed for a given reserve F.

3.6 Equilibrium

There are four markets to be cleared in this economy. The market clearing conditions are as below.

- Home goods market

$$C_{H,1} + C^*_{H,1} + (zK_1 - L_1 + L_2) = zK_1 \tag{16}$$

$$C_{H,2} + C^*_{H,2} = zK_2 \tag{17}$$

- Loans market

$$L_2^D = L_2^S \tag{18}$$

- Bank borrowing

$$B = Q \tag{19}$$

- FX market

$$\underbrace{zK_1 - \frac{\chi}{\lambda_1} - K_2 + K_1}_{\text{export}} - \underbrace{\frac{1-\chi}{\lambda_1}}_{\text{import}} \underbrace{+ Q - e_1 F}_{\text{capital flow}} = 0 \tag{20}$$

$$\underbrace{zK_2 - \frac{\chi}{\lambda_2}}_{\text{export}} - \underbrace{\frac{1-\chi}{\lambda_2}}_{\text{import}} \underbrace{- RQ + R^* e_2 F}_{\text{capital flow}} = 0 \tag{21}$$

The FX market clearing conditions are derived from combining budget constraints of each agent. These are the resource constraints of this economy.

Equilibrium Definition

An equilibrium is defined as a set of allocations $\{C_{H,1}, C_{F,1}, C_{H,2}, C_{F,2}, C^*_{H,1}, C^*_{H,2}, \lambda_1, \lambda_2, L_2, K_2, B, Q, S, \tau, \pi_F, \pi_{B,1}, \pi_{B,2}\}$ and prices $\{e_1, e_2, R\}$ that satisfies equations (1)-(10), (13)-(17), and (19)-(21) given target FX reserve F, initial capital K_1 and world interest rate R^*.

Note that (3) and (4) constitute two equations each, so the number of unknowns matches the number of equations.

Existence and Uniqueness of the Equilibrium

The equations that define the equilibrium are linear in endogenous variables. The coefficient matrix of the equation system is non-singular and a unique equilibrium exists. Formal proof is provided in Appendix A.

3.7 Effect of Reserve Accumulation

I describe the domestic consequence of reserve accumulation with the following five propositions. They characterize the effect of reserve accumulation on capital flows, bank loans,

the exchange rate, consumption, and the trade balance. The analysis is focused on the first period. The propositions are derived from the model's closed form solution. Proofs are provided in Appendix A.

Proposition 1. (Ricardian equivalence failure) *Private capital inflows only partially offset public capital outflows.*

$$0 < \frac{\partial(Q/e_1)}{\partial F} < 1$$

The numerator is private capital inflows and the denominator is public outflows, both measured in foreign currency. As the central bank channels funds abroad, the banks are short of funds to make loans and borrow more from abroad. Because of the friction in international capital flows, however, the additional borrowing is smaller than the funding shortage caused by reserve accumulation.

Proposition 1 highlights an important feature of the model. The model captures the two-way capital flows of private inflows and public outflows. It is consistent with the empirical finding of Alfaro et al. (2014) that private capital inflows are obscured by large public outflows in reserve accumulating countries.

Proposition 2. (Loan crowding-out) *Banks cut loans to firms when the central bank accumulates more reserves.*

$$\frac{\partial L_2}{\partial F} < 0$$

Thus, reserve accumulation leads banks to cut loans to firms. Loans in this model are used only for investment. Hence, this proposition can also be read as 'Reserve accumulation crowds out capital accumulation.' The following corollary compares the size of reduced loans with accumulated reserves.

Corollary 1. (Crowding-out coefficient) *The model crowding-out coefficient is calculated as below.*

$$-\frac{\partial L_2}{\partial F}\frac{1}{e_1} = \frac{R^*(1+R^*)F^2 - \frac{2R^*}{\Gamma}(1+z)(z-R^*)F + \frac{1+R^*}{\chi} + \frac{R^*(1+z)^2}{\chi\Gamma} - \frac{(z-R^*)^2}{\Gamma}}{\left(1+(\frac{z-1}{\Gamma}+F)R^*\right)\left(-R^*(1+z)F^2 + (\frac{R^*}{\chi}(\chi+z) - \frac{1}{\chi} - z)F + \frac{1+z}{\chi}(1+\frac{z(1+R^*)}{\Gamma})\right)}$$

The crowding-out coefficient is defined as the ratio of reduced loans to accumulated reserves. Using the period 1 ex-post exchange rate, the model crowding-out coefficient is derived as above. Numerical examples in the Appendix B illustrate that this coefficient is between zero and one. In the Section 4, this coefficient is empirically estimated to be 0.5 for Korea.

Proposition 3. *The exchange rate depreciates as reserves are accumulated.*

$$\frac{\partial e_1}{\partial F} > 0$$

As in Kumhof (2010) and Gabaix and Maggiori (2015), sterilized intervention can affect the exchange rate because domestic and foreign assets are imperfect substitutes. Through reserve accumulation, the central bank supplies domestic currency, demanding foreign currency. The private sector cannot undo the central bank action perfectly(Proposition 1). As a result, the exchange rate depreciates.

The exchange rate is the same as exports in this model, hence this proposition also says that exports increase after reserve accumulation.

Proposition 4. (Consumption crowding-out) *Consumption of both home goods and foreign goods is crowded out by reserve accumulation.*

$$\frac{\partial C_{H,1}}{\partial F} < 0 \text{ and } \frac{\partial C_{F,1}}{\partial F} < 0$$

Like other models of reserve accumulation, this model exhibits consumption crowding out

for home goods and foreign goods as reserve accumulation is akin to forced saving to the households.

Proposition 5. *The period 1 trade balance increases in reserve accumulation.*

$$\frac{\partial TB_1}{\partial F} > 0$$

Exports increase and imports decrease with more reserves being accumulated. As a result, the trade balance in period 1 improves. This might be a motivation behind reserve accumulation. Researches that study mercantilist view of reserve accumulation typically model dynamic benefit from running trade surplus as forced trade surplus deteriorate welfare by reducing current consumption.[10] We do not model mercantilist motivation in this paper, but the model features trade balance improvement by reserve accumulation.

The propositions summarize the effect of reserve accumulation on the economy and show the mechanism. These propositions can be illustrated by numerical examples. I solve the model numerically and provide examples in the Appendix B.

4 Empirical Framework

The model in the previous section shows that bank loans are crowded out after reserve accumulation as the central bank competes with firms in the loanable funds market under imperfect international capital mobility. Now, I examine the model prediction using bank level data from Korea.

[10] They assume learning by doing externality in the export sector. See Korinek and Serven (2010), Benigno and Fornaro (2012).

4.1 Data

The data used for the analysis in this paper come from the Bank of Korea (BOK). The BOK collects detailed bank balance sheets every month from every bank that operates in Korea. This data contributes to monetary policy implementation and is also used for compilation of the official monetary and financial statistics. The data is more detailed than the publicly available quarterly financial statements of banks.

The data encompass all banks that operate in Korea. There are 20 domestic banks and 47 foreign bank branches throughout the sample period of September 2003 to August 2008. Table 1 shows the asset compositions of different bank groups. The numbers in the table are monthly averages of sums across banks. Foreign bank branches are very different from domestic banks in size and asset composition. They are tiny in terms of total assets. The sum of 47 foreign bank branches' total assets is roughly one-tenth of that of 20 domestic banks. 26.9% of the branches' total assets are invested in safe public bonds, while 5.4% are loans to private firms. This is in contrast with domestic banks: 30.3% of domestic banks assets are loans and only 7.1% are safe bonds.

Table 1 here.

I construct two panels, A and B, to compare different banks. I exclude foreign bank branches from Panel A and study only regular domestic banks, and construct Panel B to include large foreign bank branches and compare their behavior with domestic banks. In particular, Panel A consists of the 20 regular domestic banks. The sample of banks varies from 17 to 19 throughout the period due to entry and exit. 15 banks continuously operated over the period. Panel B consists of the 20 banks in panel A plus five foreign bank branches whose average loans are larger than 500 billion KRW (roughly 0.5 billion USD). I include only the top five foreign bank branches in the sample, because other smaller branches are

not making meaningful amounts of loans or exhibit lumpy and intermittent loan provision. Summary statistics of key variables from both Panel A and Panel B are provided in Table 2.

Table 2 here.

The main dependent variable in this study is bank loans. The data distinguish loans with different types of debtors and different currencies. I consider loans to private firms only and include both Korean won loans and FX loans in the main variable $\text{Loans}_{b,m}$. b represents individual banks and m stands for month. All variables are deflated using September 2003 as the base month for inflation adjustment. The top and bottom 0.5% of loans and total assets are winsorized to reduce the impact of possible outliers.

4.2 Sample Period

The baseline analysis is based on the five years from September 2003 to August 2008, the period of massive reserve accumulation in Korea. Most of Korea's current reserve stock (371 billion USD as of December 2016) was accumulated between the 1997 Asian Crisis and the 2008 Global Financial Crisis. The available data, however, start from September 2003, and I set the five years from then to be the main sample period. However, the regression results are robust to the extension of the sample period until March 2016.

Over the sample period, Korea's reserve stock almost doubled from 136 billion USD (August 2003) to 243 billion USD (August 2008). The monthly average reserve accumulation was 1.5 billion USD, with a standard deviation of 2.7 billion USD. Figure 3 shows the monthly reserve accumulation over the sample period. Important macroeconomic statistics over the sample period are provided in Table 3.

Figure 3 here.

Table 3 here.

4.3 Empirical Strategy

I use differences-in-differences identification exploiting two bank groups, primary dealers and foreign bank branches, that are likely to be more responsive to reserve accumulation.

First, I compare primary dealer banks with non-primary dealer banks. Every July, the BOK announces a group of banks that can participate in the primary market of sterilization securities for one year, beginning the following month (August). The impact of reserve accumulation and sterilization on the funds market, if any, starts from the primary market of sterilization securities. The primary dealers initially take over the securities, and hence they are more likely to reduce loans than the other banks. In addition, the primary dealers have strong incentives to cooperate with the central bank on sterilization. The primary dealers are not forced to buy securities, but are instead offered price incentives, which makes the dealership profitable.[11] The primary dealership is renewed based on past transaction records and is made explicit when BOK announces primary dealers each year. If the dealership is of some value to the banks, they need to take over significant amounts of the securities when they are issued after reserve accumulation. Consequently, they are more prone to reduce loans.

Second, I check whether foreign bank branches are different in response to reserve accumulation than other ordinary domestic banks. It is a well known fact that foreign bank branches specialize in trading safe public securities. Making loans is not their main business,

[11] A former monetary policy committee member documents, however, that before 1990s it was common for financial intermediaries to be forced to buy central bank bills (Ha, 2011). They had no option but to take over the securities and reduce lending to firms.

although they do provide loans to firms. This can be confirmed from comparison of their asset composition with that of domestic banks as already explained previously in Table 1. Thus, one can expect that the loan growth rate would be lower in foreign bank branches than in domestic banks, because those branches would have taken over a significant portion of central bank securities after reserve accumulation.

5 Results

5.1 Bank Lending after Reserve Accumulation

I begin by estimating the change in the loan growth rate after reserve accumulation. To control for other factors that can influence bank lending, I run panel regressions with fixed effects and controls. The baseline regression equation is as follows:

$$\Delta \ln \text{Loans}_{b,m} = \alpha_b + \alpha_q + \lambda m + \beta \text{RA}_{m-1} + \gamma' \mathbf{Bank}_{b,m-1} + \theta' \mathbf{Macro}_{m-1} + \epsilon_{b,m} \qquad (22)$$

where α_b is a bank fixed effect; α_q is a year-by-quarter fixed effect; and m is a linear trend variable. RA is Korea's monthly transactions of FX reserves, as reported in the balance of payments.

The baseline dependent variable is the change in the logarithm of a bank's loans. Different studies use different forms of the dependent variable in the literature. The change in log loans is used in Jiménez et al. (2017). The log level of loans is also popular: see Baskaya et al. (2017) and Jiménez et al. (2014). The ratio of the change in loans to total assets is used in the International Banking Research Network's papers: see Buch and Goldberg (2014). When the dependent variable is in the change in log form, the bank fixed effect absorbs the different trends of loans for individual banks, whereas the same bank fixed effect absorbs different, time-invariant levels of loans when the regressand is the log level of loans.

The change in log form, combined with bank fixed effects, assigns different trends of loan growth for each bank, and thus absorbs more variation in the regressand. Over the sample period, different banks had different trends of loan growth in the data, which is seemingly unrelated to reserve accumulation because monthly reserve accumulation had no trend, as can be seen from Figure 3. Thus, the change in log form is more suitable for this research. I use the change in log loans form, although the regression results are robust to the use of other forms of the dependent variable.

The year-by-quarter fixed effect α_q sets different intercepts for each quarter, and I exploit only the within-quarter variations in loan growth rate to avoid influence of any omitted variables that varies by quarter. The fixed effect is expected to absorb most of the business cycle effects. The linear trend absorbs within-quarter linear trends that are common across banks. In addition to the time and unit fixed effects, I include controls for individual bank characteristics. **Bank** is a set of bank level control variables that are standard in the literature. This includes banks' log total assets, capital ratios and core deposit ratios.

The timing and magnitude of reserve accumulation are decided by the central bank, presumably as a function of macroeconomic variables. Although the year-by-quarter fixed effect and time trend absorb quarterly differences and trends in loan growth, I further control for other macroeconomic factors that might affect bank loans. The vector **Macro** includes inflation, the real policy rate and the real exchange rate.[12] RA and other independent variables are lagged one month in order to mitigate endogeneity issues.

Standard errors are clustered by banks in every regression. Bertrand et al. (2004) warns that autocorrelation in high-frequency panel data generate bias in the estimation of standard errors. Although the dependent variable is first differenced, I allow for arbitrary correlation of error terms within each bank by clustering standard errors at the bank level. This would correct for possible biases due to autocorrelation issues. In addition, all the regressions are based on weighted least squares using bank size as the weight.

[12]The regression results without real policy rate and real exchange rate are not very different from the main regression results.

Table 4 presents the results. Each column uses different forms of the dependent variable. Column (1) uses the main form, the change in log loans. Results for the log level of loans are shown in column (2). Column (3) uses the ratio of the change in loans with respect to total assets. Regardless of how I define the regressand, the coefficient is negative and significant. For both Panel A and Panel B, reserve accumulation is negatively associated with loan growth. The coefficients are statistically significant at the 1% level. The coefficients from Panel B are more negative than those of Panel A in all three columns.

The coefficients are also economically significant. Over the sample period, the standard deviation of monthly real reserve accumulation is 2.5 billion USD at September 2003 price. Using the coefficient from column (1) for Panel A, I calculate that a 2.5 billion USD reserve accumulation is associated with a decrease in the average loan growth rate of 0.40 percentage points. This is comparable with the average monthly loan growth rate of 0.69%.

Table 4 here.

I then estimate the crowding-out coefficient, proposed in Corollary 1. It is defined as the amount of reduction in loans after one dollar of reserve accumulation. I apply the coefficient from column (1) to the total loans of all domestic banks and convert the result to USD to compare with accumulated reserves:

$$\underbrace{-0.0161}_{\text{coefficient}} \times \underbrace{301.7 \text{ trillion KRW}}_{\text{total loans to private firms}^*} \div \underbrace{973 \text{ KRW/USD}}_{\text{real exchange rate}^*} = \underbrace{-5.0 \text{ billion USD}}_{\text{decrease in loans after 10 billion RA}}$$

* as of March 2006 (center of the sample period)

For total loans and the real exchange rate, I use the data of March 2006, which is the center of the sample period. The unit of RA is 10 billion USD in the regression, so the crowding-out coefficient is estimated as 0.5. This means that bank loans decline by 50 cents after one extra dollar of reserve accumulation.

5.2 Differences-in-Differences

Although the previous regression differenced out unobserved heterogeneity and quarterly changes in the macro environment using fixed effects, it still cannot completely rule out endogeneity. To make a causal statement from this regression, we need a strong assumption that other factors that are not spanned by the included fixed effects and controls are not correlated with reserve accumulation. In this section, I use differences-in-differences to identify the causal relationship between reserve accumulation and bank lending.

I exploit bank heterogeneity by interacting bank dummies with reserve accumulation:

$$\Delta \ln \text{Loans}_{b,m} = \alpha_b + \alpha_m + \beta_1 PD_b \times \text{RA}_{m-1} + \beta_2 FBB_b \times \text{RA}_{m-1} + \gamma' \mathbf{Bank}_{b,m-1} + \theta' \mathbf{Bank}_b \times \text{RA}_{m-1} + \epsilon_{b,m} \quad (23)$$

PD_b is an indicator variable that is equal to one if bank b had been a primary dealer for more than four years out of five-year sample period. By setting the threshold at 48 months, I compare 6 primary dealer group banks with 14 other banks in Panel A, and 7 versus 18 in Panel B. FBB_b is one for foreign bank branches and zero for domestic banks. Bank control variables are also interacted with reserve accumulation to allow for possible heterogeneous responses. These variables are averaged over the sample period before being interacted with reserve accumulation. Interaction terms are normalized with respect to the mean across all banks. The main regressor in this specification varies over both banks and months, so I use year-by-month fixed effects (α_m). Hence, the linear trend and macro controls are not carried over from the previous specification. α_m absorbs the effect of monthly changes in the macroeconomic environment.

Table 5 here.

Table 5 shows the results. Columns (1)-(2) are regressions on Panel A, and (3)-(4) are regressions on Panel B. Note that columns (1) and (3) have a direct RA term and do

not include year-by-month fixed effects. Instead, they have year-by-quarter fixed effects, macro controls and a linear trend. Columns (2) and (4) have year-by-month fixed effects. The coefficient to RA in column (1) is similar to that of Table 4. It shows that reserve accumulation is negatively associated with the loan growth rate. Looking at the interaction terms in column (1), we see that primary dealer group banks reduce loans more after reserve accumulation than non-primary dealer banks. This result remains valid in column (2), where I absorb time series variation using year-by-month fixed effects.

The regressions on Panel B suggest similar results about the primary dealers. Now the coefficients are more significant both economically and statistically. A new result is that the coefficient on the interaction of RA with the foreign bank branch dummy is negative and significant. Column (3) suggests that foreign bank branches cut loans much more than domestic banks after reserve accumulation. This result remains valid in column (4), which includes year-by-month fixed effects.

The result is also economically significant. Column (4) indicates that the loan growth rate declines by 0.4 percentage points more in primary dealer banks than the other banks after one standard deviation reserve accumulation (2.5 billion USD). Foreign bank branches cut loans by 1.6 percentage points more compared with domestic banks.

5.3 Robustness Checks

The regression results are robust to various changes. I report additional results in this section. First, I extend the sample period up to March 2016 and examine whether the results remain valid after including more recent data. The major obstacles are the Global Financial Crisis in 2008-2009 and the European Debt Crisis in 2010-2011. During these crises, Korea decumulated reserves significantly and frequently to protect its financial system from substantial capital outflows. The theoretical model in Section 3 does not imply any asymmetry between accumulation and decumulation, and hence, reserve decumulation should increase

loans. However, decumulation is typically done in a time of increased uncertainty, which leads to decline in loan growth. This makes the identification difficult with decumulation episodes.

I use a time dummy to deal with the crisis periods. Crisis_m is equal to one between September 2008 and December 2011. This period encompasses major decumulation episodes due to the two crises. The crisis dummy is interacted with the main regressors. The primary dealer dummy threshold is set to 115 months as the sample period increases to 151 months. The regression equation with the crisis dummy and triple interaction terms is as follows:

$$\begin{aligned}\Delta \ln \text{Loans}_{b,m} = \alpha_b + \alpha_m + \beta_1 PD_b \times \text{RA}_{m-1} + \beta_2 \text{Crisis}_m \times PD_b \times \text{RA}_{m-1} \\ + \beta_3 FBB_b \times \text{RA}_{m-1} + \beta_4 \text{Crisis}_m \times FBB_b \times \text{RA}_{m-1} \\ + \gamma' \mathbf{Bank}_{b,m-1} + \theta' \mathbf{Bank}_b \times \text{RA}_{m-1} + \epsilon_{b,m} \end{aligned} \tag{24}$$

Table 6 shows the results. Overall, the main results remain valid in the normal time. Bank lending is negatively associated with reserve accumulation (columns (1) and (4)). After reserve accumulation, primary dealer banks and foreign bank branches cut lending more compared to non-primary dealer banks and domestic banks, respectively (columns (3) and (6)). The negative correlation between reserve accumulation and bank lending becomes weaker in the crisis period, as expected. The difference between different bank groups also weakens in the crisis time.

Table 6 here.

Table 7 presents results using a different threshold for primary dealer dummy. Now the sample period is from September 2003 to August 2008, and the threshold is set to 36 months rather than 48 months. I compare banks which had been primary dealers for more than three years with the other banks. We have 9 primary dealer group banks and 11 other banks in Panel A with this criteria, and 10 versus 15 in Panel B. The regression results are by and

large similar with the results in Table 5. The size of the coefficients on main interaction terms changes a little, but they are still negative and statistically significant.

Table 7 here.

The sample period is cut at August 2008, just before the Global Financial Crisis. Reserve decumulation over the financial crisis, however, started as early as January 2008. The financial crisis was a period of both massive decumulation and financial market disorder. As a robustness check, I exclude the entire year 2008 from the sample and avoid any influence from the decumulation and disorder. Since the sample period shrinks to 52 months, the primary dealer dummy threshold is set to 36 months. Table 8 shows the results. Compared with the main results presented in Tables 4 and 5, coefficients are larger in absolute value and the statistical significance for primary dealer dummy also increases. The results remain valid.

Table 8 here.

6 Conclusion

This paper investigates an indirect cost of FX reserve accumulation: reduction in bank loans to firms. Based on a simple analytical model, I suggest that reserve accumulation crowds out bank lending under imperfect international capital mobility. This is empirically tested using bank level micro data from Korea. I find that the bank loan growth rate declined significantly after reserve accumulation. Causation is identified from the differences-in-differences framework. The analysis shows that bank loans are reduced more in primary dealer banks and foreign bank branches than in non-primary dealer banks and domestic banks, respectively.

This paper provides an important policy implication on how sterilized reserve accumulation can help open economies deal with capital inflows. There is a view that capital inflows lead to asset price inflation and credit expansion. Policy makers believe that capital inflows are expansionary. This is supported by empirical evidence in the literature. For example, Baskaya et al. (2017) show that capital inflows decrease the cost of borrowing and lead to credit expansion.

The evidence presented in this paper shows that sterilized reserve accumulation has contractionary effects. Banks reduce loans to firms and hold more risk-free central bank debts, and firms end up borrowing less from the banks. Reserve accumulation not only works against exchange rate appreciation, but also partially offsets the expansionary effect of capital inflows. This explains why reserve accumulation is a favored tool to cope with capital inflows in many countries.

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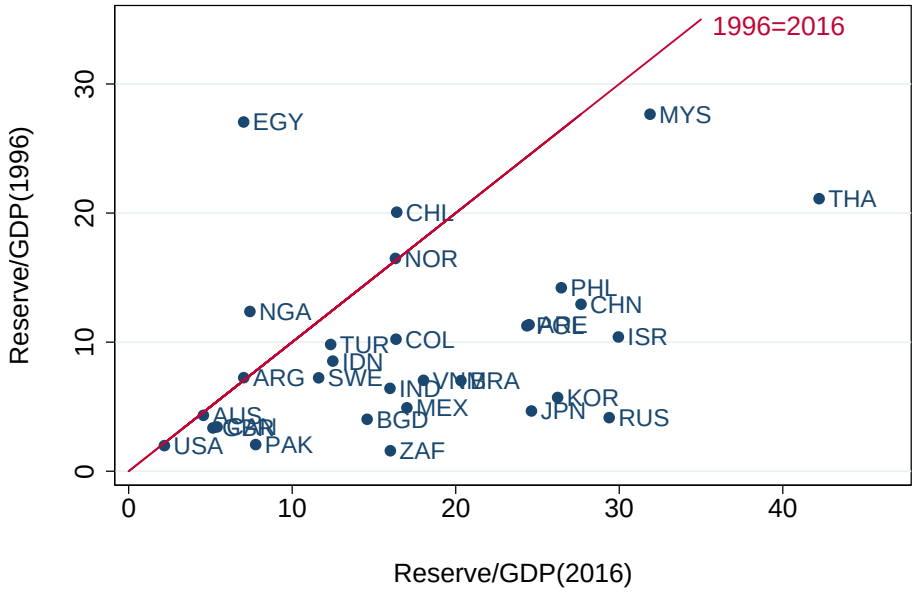
Figure 1: Reserve to GDP Ratio Changes between 1996 - 2016



NOTES: Data is from the World Bank. 45 degree line is provided for comparison. Eurozone countries are excluded. Very small countries with 2016 GDP smaller than 200 billion USD are excluded. Saudi Arabia(10%, 85%), Singapore(80%, 85%), and Switzerland(21%,103%) are not displayed due to extreme values. Total of 30 countries are shown in the plot. The average increase of the ratio in the 30 countries shown in the graph is 7.2 percent points.

Figure 2: Model Outline

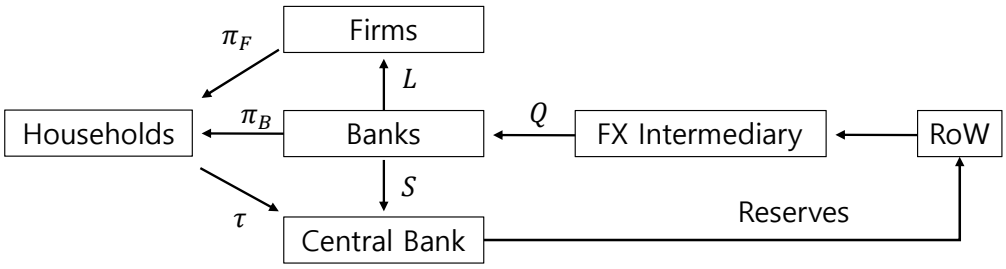
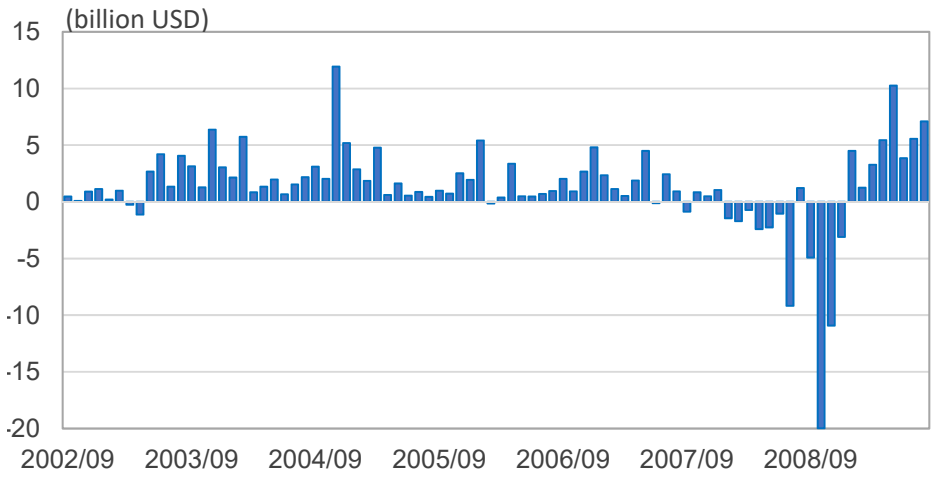


Figure 3: Monthly Reserve Accumulation over the Sample Period



NOTES: The data is from the Bank of Korea. The sample period is from September 2003 to August 2008, while this graph shows the period from September 2002 to August 2009.

Table 1: Bank Asset Composition

	N	Loans to private firms	Public bonds	Corporate bonds	Total assets
Domestic banks	20	326.8	77.0	50.2	1077.5
		(30.3)	(7.1)	(4.7)	(100.0)
Foreign bank branches	47	6.2	30.8	0.8	114.6
		(5.4)	(26.9)	(0.7)	(100.0)
Top 5 branches	5	3.1	3.8	0.4	27.1
		(11.5)	(14.0)	(1.6)	(100.0)

NOTES: The numbers are monthly average of sum across bank groups. Values are in 2003.9 real KRW. Numbers in parentheses are composition ratios. Loans cover only loans to private firms. Public bonds include government bonds and central bank bonds.

Table 2: Summary Statistics

	Mean	SD	P25	P50	P75
Panel A: 20 domestic banks					
Total assets(tril. KRW)	62.58	52.72	16.39	54.08	98.40
Log total assets	17.41	1.23	16.61	17.81	18.40
Loans to private firms(tril. KRW)	18.98	16.70	5.93	11.04	34.14
Δ ln loans	0.01	0.02	0.00	0.01	0.02
Core deposit ratio	0.53	0.18	0.46	0.57	0.65
Capital ratio	0.06	0.03	0.05	0.06	0.07
Panel B: Panel A + 5 branches					
Total assets(tril. KRW)	51.70	52.31	9.20	22.16	85.53
Log total assets	17.02	1.39	16.03	16.91	18.26
Loans to private firms(tril. KRW)	15.44	16.64	1.65	7.53	22.22
Δ ln loans	0.01	0.06	-0.01	0.01	0.02
Core deposit ratio	0.45	0.24	0.25	0.51	0.63
Capital ratio	0.06	0.03	0.05	0.06	0.07

NOTES: P25, P50 and P75 refer to 25th, 50th and 75th percentile, respectively.

Table 3: Macro Aggregates over the Sample Period

	Mean	SD	P25	P50	P75
Reserve accumulation(10 bil. USD)	0.15	0.25	0.05	0.10	0.23
Real GDP growth	1.2	0.6	0.6	1.3	1.7
Policy rate	4.1	0.6	3.5	4.0	4.5
Real exchange rate fluctuation	-0.002	0.017	-0.013	-0.004	0.009

NOTES: P25, P50 and P75 refer to 25th, 50th and 75th percentile, respectively.

Table 4: Response of Bank Lending to Reserve Accumulation

	(1) $\Delta \ln(\text{loans})$	(2) $\ln(\text{loans})$	(3) $\frac{\Delta \text{loans}_{b,m}}{\text{assets}_{b,m-1}}$
Panel A			
RA_{m-1}	-0.0161***	-0.0174***	-0.469***
	(0.0038)	(0.0040)	(0.1157)
Observations	1,013	1,013	1,013
Number of Banks	20	20	20
R-squared	0.241	0.847	0.22
Panel B			
RA_{m-1}	-0.0252***	-0.0225***	-0.567***
	(0.0086)	(0.0049)	(0.1887)
Observations	1,257	1,257	1,257
Number of Banks	25	25	25
R-squared	0.0671	0.727	0.062
Macro controls & trend	yes	yes	yes
Bank controls	yes	yes	yes
Year-by-Quarter F.E.	yes	yes	yes
Bank F.E.	yes	yes	yes

NOTES: Regression (1)-(3) are on Panel A, and (4)-(6) are on Panel B. The sample period is 2003.9-2008.8. RA is the reserve accumulation measured in 10 billion USD in the balance of payments. Loans and total assets are winsorized at the 0.5 and 99.5 percentiles. A constant is included in every regression but its coefficient is left unreported. Bank controls include log assets, core deposit ratio and capital ratio. Macro controls include inflation, real policy rate, and the real exchange rate. The coefficients for these controls are not reported. Regressions are all weighted-least squares, where weights are equal to the bank asset size. Standard errors are clustered by bank. ***, ** and * denote significance at 1%, 5%, 10%, respectively.

Table 5: Differences in Bank Lending after Reserve Accumulation

	(1)	(2)	(3)	(4)
	$\Delta \ln$(loans)	$\Delta \ln$(loans)	$\Delta \ln$(loans)	$\Delta \ln$(loans)
RA_{m-1}	-0.0157***		-0.0259***	
	(0.0035)		(0.0080)	
Primary Dealer$_b \times RA_{m-1}$	-0.00874*	-0.00891*	-0.0150**	-0.0154**
	(0.0050)	(0.0050)	(0.0055)	(0.0058)
Foreign Bank Branches$_b \times RA_{m-1}$			-0.0659***	-0.0633***
			(0.0101)	(0.0101)
Observations	1,013	1,013	1,257	1,257
Number of Banks	20	20	25	25
R-squared	0.251	0.374	0.076	0.114
Macro controls & trend	yes	-	yes	-
Bank controls	yes	yes	yes	yes
Year-by-Quarter F.E.	yes	-	yes	-
Year-by-Month F.E.	no	yes	no	yes
Bank F.E.	yes	yes	yes	yes

NOTES: Regression (1)-(2) are on Panel A, and (3)-(4) are on Panel B. The sample period is 2003.9-2008.8. RA is the reserve accumulation measured in 10 billion USD in the balance of payments. Primary Dealer$_b = 1$ if a bank has been a primary dealer for more than 48 months. Loans and total assets are winsorized at the 0.5 and 99.5 percentiles. All interaction terms are demeaned. A constant is included in every regression but its coefficient is left unreported. Fixed effects and macro controls are either included(yes), not included(no), or spanned by another set of effects(-). Bank controls include log assets, core deposit ratio, capital ratio and their interactions with reserve accumulation. Macro controls include inflation, real policy rate and the real exchange rate. The coefficients for these controls are not reported. Regressions are all weighted-least squares, where weights are equal to the bank asset size. Standard errors are clustered by bank. ***, ** and * denote significance at 1%, 5%, 10%, respectively.

Table 6: September 2003 to March 2016

	(1)	(2)	(3)	(4)	(5)	(6)
	Δ ln(loans)	Δ ln(loans)	Δ ln(loans)	Δ ln(loans)	Δ ln(loans)	Δ ln(loans)
RA_{m-1}	-0.00978***	-0.00967***		-0.0138*	-0.0142*	
	(0.0027)	(0.0026)		(0.0080)	(0.0076)	
$Crisis_m \times RA_{m-1}$	0.00657**	0.00666**		0.0171*	0.0180**	
	(0.0031)	(0.0031)		(0.0083)	(0.0070)	
Primary $Dealer_b \times RA_{m-1}$		-0.00676*	-0.00830**		-0.00570	-0.00742*
		(0.0037)	(0.0038)		(0.0036)	(0.0038)
$Crisis_m \times$ Primary $Dealer_b \times RA_{m-1}$		0.00565	0.00717		0.00484	0.00650
		(0.0049)	(0.0050)		(0.0045)	(0.0046)
Foreign Bank $Branches_b \times RA_{m-1}$					-0.0225*	-0.0219*
					(0.0117)	(0.0117)
$Crisis_m \times$ Foreign Bank $Branches_b \times RA_{m-1}$					0.0416***	0.0413**
					(0.0147)	(0.0149)
Observations	2,560	2,560	2,560	3,168	3,168	3,168
Number of Banks	20	20	20	25	25	25
R-squared	0.211	0.215	0.377	0.0611	0.0639	0.117
Macro controls & trend	yes	yes	-	yes	yes	-
Bank controls	yes	yes	yes	yes	yes	yes
Year-by-Quarter F.E.	yes	yes	-	yes	yes	-
Year-by-Month F.E.	no	no	yes	no	no	yes
Bank F.E.	yes	yes	yes	yes	yes	yes

NOTES: Regression (1)-(3) are on Panel A, and (4)-(6) are on Panel B. The sample period is 2003.9-2016.3. RA is the reserve accumulation measured in 10 billion USD in the balance of payments. Primary $Dealer_b = 1$ if a bank has been a primary dealer for more than 115 months. Loans and total assets are winsorized at the 0.5 and 99.5 percentiles. All interaction terms are demeaned. A constant is included in every regression but its coefficient is left unreported. Fixed effects and macro controls are either included(yes), not included(no), or spanned by another set of effects(-). Bank controls include log assets, core deposit ratio, capital ratio and their interaction with reserve accumulation. Macro controls include inflation, real policy rate and the real exchange rate. The coefficients for these controls are not reported. Regressions are weighted-least squares, where weights are equal to the bank asset size. Standard errors are clustered by bank. ***, ** and * denote significance at 1%, 5%, 10%, respectively.

Table 7: Different Threshold for Primary Dealer Dummy

	(1)	(2)	(3)	(4)
	$\Delta \ln$(loans)	$\Delta \ln$(loans)	$\Delta \ln$(loans)	$\Delta \ln$(loans)
RA_{m-1}	-0.0157***		-0.0258***	
	(0.0034)		(0.0079)	
Primary $\text{Dealer}_b \times RA_{m-1}$	-0.00657*	-0.00784**	-0.0105*	-0.0115*
	(0.0034)	(0.0033)	(0.0058)	(0.0064)
Foreign $\text{Bank Branches}_b \times RA_{m-1}$			-0.0731***	-0.0701***
			(0.0105)	(0.0105)
Observations	1,013	1,013	1,257	1,257
Number of Banks	20	20	25	25
R-squared	0.251	0.373	0.0758	0.114
Macro controls & trend	yes	-	yes	-
Bank controls	yes	yes	yes	yes
Year-by-Quarter F.E.	yes	-	yes	-
Year-by-Month F.E.	no	yes	no	yes
Bank F.E.	yes	yes	yes	yes

NOTES: The sample periods are 2003.9-2008.8. in columns (1)-(2) and 2003.9-2007.12 in columns (3)-(4). Columns (1)-(2) are on panel A, and (3)-(4) are on panel B. RA is the reserve accumulation measured in 10 billion USD in the balance of payments. $\text{Primary Dealer}_b = 1$ if a bank has been a primary dealer for more than 36 months. Loans and total assets are winsorized at the 0.5 and 99.5 percentiles. All interaction terms are demeaned. A constant is included in every regression but its coefficient is left unreported. Fixed effects and macro controls are either included(yes), not included(no), or spanned by another set of effects(-). Bank controls include log assets, core deposit ratio, capital ratio and their interaction with reserve accumulation. Macro controls include inflation, real policy rate and the real exchange rate. The coefficients for these controls are not reported. Regressions are weighted-least squares, where weights are equal to the bank asset size. Standard errors are clustered by bank. ***, ** and * denote significance at 1%, 5%, 10%, respectively.

Table 8: September 2003 to December 2007

	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta \ln$(loans)	$\Delta \ln$(loans)	$\Delta \ln$(loans)	$\Delta \ln$(loans)	$\Delta \ln$(loans)	$\Delta \ln$(loans)
RA_{m-1}	-0.0191***	-0.0187***		-0.0196***	-0.0205***	
	(0.0044)	(0.0034)		(0.0043)	(0.0059)	
Primary $\text{Dealer}_b \times RA_{m-1}$		-0.0151***	-0.0166***		-0.0183***	-0.0206***
		(0.0044)	(0.0045)		(0.0062)	(0.0071)
Foreign $\text{Bank Branches}_b \times RA_{m-1}$					-0.0730***	-0.0683***
					(0.0112)	(0.0112)
Observations	877	877	877	1,089	1,089	1,089
Number of Banks	20	20	20	25	25	25
R-squared	0.245	0.256	0.377	0.0722	0.0807	0.12
Macro controls & trend	yes	yes	-	yes	yes	-
Bank controls	yes	yes	yes	yes	yes	yes
Year-by-Quarter F.E.	yes	yes	-	yes	yes	-
Year-by-Month F.E.	no	no	yes	no	no	yes
Bank F.E.	yes	yes	yes	yes	yes	yes

NOTES: Regression (1)-(3) are on Panel A, and (4)-(6) are on Panel B. The sample period is 2003.9-2007.12. RA is the reserve accumulation measured in 10 billion USD in the balance of payments. Primary $\text{Dealer}_b = 1$ if a bank has been a primary dealer for more than 36 months. Loans and total assets are winsorized at the 0.5 and 99.5 percentiles. All interaction terms are demeaned. A constant is included in every regression but its coefficient is left unreported. Fixed effects and macro controls are either included(yes), not included(no), or spanned by another set of effects(-). Bank controls include log assets, core deposit ratio, capital ratio and their interaction with reserve accumulation. Macro controls include inflation, real policy rate and the real exchange rate. The coefficients for these controls are not reported. Regressions are weighted-least squares, where weights are equal to the bank asset size. Standard errors are clustered by bank. ***, ** and * denote significance at 1%, 5%, 10%, respectively.

Appendix A Proofs of Propositions

This model yields closed form solution for endogenous variables. The propositions are derived by differentiating the solution. I start with the minimal set of equations that defines equilibrium:

$$zK_1 - \frac{1}{\lambda_1} - L_2 + Q - e_1 F = 0 \tag{A.1}$$

$$zK_1 + zL_2 - \frac{1}{\lambda_2} - zQ + R^* e_2 F = 0 \tag{A.2}$$

$$Q = \frac{z}{\Gamma} e_1 - \frac{R^*}{\Gamma} e_2 \tag{A.3}$$

$$\frac{\chi}{\lambda_1} = zK_1 - L_2 - e_1 \tag{A.4}$$

$$\frac{\chi}{\lambda_2} + e_2 = zK_1 + zL_2 \tag{A.5}$$

(A.1) and (A.2) are the resource constraints and (A.4) and (A.5) are home goods market clearing conditions combined with households' optimal behavior. Plugging (A.3)-(A.5) into (A.1) and (A.2), one can get two linear equations with two unknowns e_1 and L_2.

$$\underbrace{\left(\frac{1}{\chi} + \frac{z - R^*}{\Gamma} - F\right)}_{A} e_1 + \underbrace{\left(\frac{1-\chi}{\chi} - \frac{(1+z)R^*}{\Gamma}\right)}_{B} L_2 = \frac{1-\chi}{\chi} zK_1 \tag{A.6}$$

$$\underbrace{\left(\frac{1}{\chi} + \frac{z(R^* - z)}{\Gamma} + R^* F\right)}_{C} e_1 + \underbrace{\left(\frac{1}{\chi} + z + (1+z)R^*\left(\frac{z}{\Gamma} + F\right)\right)}_{D} L_2 = \frac{1-\chi}{\chi} zK_1 \tag{A.7}$$

A, B, C and D are the references to the corresponding terms. A unique solution to this system of equations exists if the coefficients matrix is non-singular.

Existence of a Unique Equilibrium. *There exists a unique equilibrium.*

If $AD - BC \neq 0$, then there exists a unique equilibrium. The determinant is derived as a quadratic function of F:

$$AD - BC = -R^*(1+z)F^2 + \left(\frac{R^*}{\chi}(\chi + z) - \frac{1}{\chi} - z\right)F + \frac{1+z}{\chi\Gamma}(z(1+R^*) + \Gamma) \tag{A.8}$$

The two values of F that make the determinant zero are either negative or greater than one. We are assuming that FX reserve F cannot be negative, and also it is smaller than total export which is one in foreign currency. Therefore, there always exist a unique equilibrium.

Proposition 1. (Ricardian equivalence failure) *Private capital inflows cannot fully offset public capital outflows.*

$$0 < \frac{\partial(Q/e_1)}{\partial F} < 1$$

Proof.

$$\begin{aligned} \frac{Q}{e_1} &= \frac{z - R^*}{\Gamma} - \frac{R^*(1+z)}{\Gamma}\frac{(A-C)}{(D-B)} \\ \frac{\partial(Q/e_1)}{\partial F} &= \frac{R^*[(\Gamma-2)(1+R^*)+(1+z)^2]}{(\Gamma+(1+z)R^*+R^*\Gamma F)^2} \end{aligned} \tag{A.9}$$

Within the range of parameters and exogenous variables, (A.10) is positive and less than one. □

Proposition 2. *Banks cut loans to firms when the central bank accumulates more reserves.*

$$\frac{\partial L_2}{\partial F} < 0$$

Proof.

$$L_2 = \frac{A-C}{AD-BC}\frac{1-\chi}{\chi}zK_1 \tag{A.10}$$

$$\frac{\partial L_2}{\partial F} = \frac{\frac{1-\chi}{\chi}zK_1(1+z)}{(AD-BC)^2}\left[-R^*(1+R^*)F^2 + \frac{2}{\Gamma}R^*(1+z)(z-R^*)F - \frac{1+R^*}{\chi} - \frac{R^*(1+z)^2}{\chi\Gamma} + \frac{(z-R^*)^2}{\Gamma}\right]$$

The terms in the square brackets are negative within the assumed range of parameters. □

Corollary 1. (Crowding-out coefficient) *The model crowding-out coefficient is calculated as below.*

$$\begin{aligned}
-\frac{\partial L_2}{\partial F}\frac{1}{e_1} &= \frac{1+z}{(AD-BC)(D-B)}\left[R^*(1+R^*)F^2 - \tfrac{2}{\Gamma}R^*(1+z)(z-R^*)F + \tfrac{1+R^*}{\chi} + \tfrac{R^*(1+z)^2}{\chi\Gamma} - \tfrac{(z-R^*)^2}{\Gamma}\right] \\
&= \frac{R^*(1+R^*)F^2 - \frac{2R^*}{\Gamma}(1+z)(z-R^*)F + \frac{1+R^*}{\chi} + \frac{R^*(1+z)^2}{\chi\Gamma} - \frac{(z-R^*)^2}{\Gamma}}{\left(1+(\frac{z-1}{\Gamma}+F)R^*\right)\left(-R^*(1+z)F^2 + (\frac{R^*}{\chi}(\chi+z) - \frac{1}{\chi} - z)F + \frac{1+z}{\chi}(1+\frac{z(1+R^*)}{\Gamma})\right)}
\end{aligned}$$

Proposition 3. *Exchange rate depreciates as reserve is being accumulated.*

$$\frac{\partial e_1}{\partial F} > 0$$

Proof.

$$e_1 = \frac{D-B}{AD-BC}\frac{1-\chi}{\chi}zK_1 \tag{A.11}$$

$$\begin{aligned}
\frac{\partial e_1}{\partial F} &= \frac{\frac{1-\chi}{\chi}zK_1(1+z)}{(AD-BC)^2}\Bigg[R^*(AD-BC) \\
&\qquad -\left(\frac{R^*}{\chi}(\chi+z) - \frac{1}{\chi} - z - 2R^*(1+z)F\right)\left(1 + \frac{R^*(z-1)}{\Gamma} + R^*F\right)\Bigg] \\
&= \frac{\frac{1-\chi}{\chi}zK_1(1+z)}{(AD-BC)^2}\Bigg[(1+z)R^{*2}F^2 + 2R^*(1+z)\frac{(z-1)R^*+\Gamma}{\Gamma}F + \frac{R^*(1+z)}{\chi} \\
&\qquad + \frac{(z-1)R^*+\Gamma}{\Gamma}(z-R^*) + \frac{1}{\chi\Gamma}(z^2R^{*2} + 2(zR^* + zR^{*2}) - R^* - \Gamma(R^*z-1))\Bigg] > 0
\end{aligned}$$

□

Proposition 4. (Consumption crowding-out) *Consumption of both home goods and foreign goods is crowded out by reserve accumulation.*

$$\frac{\partial C_{H,1}}{\partial F} < 0, \text{ and } \frac{\partial C_{F,1}}{\partial F} < 0$$

Proof.

$$\begin{aligned} e_1 C_{F,1} &= \pi_{B,1} - C_{H,1} \\ &= Q - S + e_1 \\ C_{F,1} &= \frac{Q}{e_1} - F + 1 \end{aligned}$$

Hence, $\dfrac{\partial C_{F,1}}{\partial F} = \dfrac{\partial Q/e_1}{\partial F} - 1$ and from the proposition 1, this is less than one.

From equation (3), if $\dfrac{\partial e_1 C_{F,1}}{\partial F} < 0$, then $\dfrac{\partial C_{H,1}}{\partial F} < 0$. By proposition 3, $\dfrac{\partial e_1}{\partial F}$ is positive and it was proven above that $\dfrac{\partial C_{F,1}}{\partial F} < 0$. Therefore, $\dfrac{\partial e_1 C_{F,1}}{\partial F} < 0$ and $\dfrac{\partial C_{H,1}}{\partial F} < 0$. □

Proposition 5. *Trade balance in period 1 improves as the central bank accumulates reserves.*

$$\frac{\partial TB_1}{\partial F} > 0$$

Proof. Trade balance of period 1 measured in domestic currency is same as $e_1 - e_1 C_{F,1}$. e_1 is exports and it is increasing in reserve accumulation(proposition 3). $e_1 C_{F,1}$ is import, and it was shown in the proof of proposition 4 that $\dfrac{\partial e_1 C_{F,1}}{\partial F} < 0$. Hence, export increases and import decreases. Together, trade balance improves. □

The propositions can be summarized in the following national account identities. The arrows show qualitative changes after reserve accumulation.

$$Y = \underbrace{C}_{\downarrow} + \underbrace{I}_{\downarrow} + \underbrace{X}_{\uparrow} - \underbrace{M}_{\downarrow}$$

$$\underbrace{TB}_{\uparrow} = CA = FA = \underbrace{e_1 F - Q}_{\uparrow}$$

Appendix B Numerical Illustrations of the Model

I include here a brief numerical simulation to show numerically how the economic forces work. Table 9 shows the chosen parameters. χ is 0.5, so the households weigh the two consumption goods equal. Productivity z is chosen to be 10% greater than the world interest rate R^*. 0.1 for Γ is following Gabaix and Maggiori (2015).[13] The initial capital stock is chosen to be two to make the exchange rate around one.

Table 9: Parameters for numerical example

χ	z	R^*	Γ	K_1
0.5	1.1	1.0	0.1	2.0

I calculate equilibria for 11 different levels of FX reserve accumulation from zero to one. Figure 4 shows the outcome. Each panel corresponds to proposition 1 to 5 and corollary 1. Panel 1 shows that private inflows increase with public outflows, but cannot fully offset the outflows. The next panels show that bank loans decline, exchange rate depreciates, consumption is crowded out and trade balance improves. The crowding-out coefficient is within the range of 0.3 to 0.5 and it is broadly compatible with the empirical finding.

[13] They note that $\Gamma = 0.1$ is "in broad congruence with the experience of Israel and Switzerland during the recent financial crisis."

Figure 4: Numerical Illustrations