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A GROWTH PERSPECTIVE ON FOREIGN RESERVE ACCUMULATION

GONG CHENG
Sciences Po
and
European Stability Mechanism

Based on a dynamic open-economy macroeconomic model, this paper analyzes the motive for foreign reserve accumulation in fast-growing emerging economies. The demand for foreign reserves stems from the interaction between productivity growth and underdevelopment of the domestic financial market. As domestic firms are credit-constrained, domestic saving instruments are necessary to increase their retained earnings in order to invest in capital. The central bank plays the role of a financial intermediary and provides liquid public bonds while investing the bond proceeds abroad in the form of foreign reserves. Foreign reserve accumulation is thus part of a catching-up strategy in an economy facing financial frictions. During economic transition, foreign reserve accumulation is proved to be welfare-improving as long as private capital flows are controlled. This joint strategy enables the central bank to channel sufficient external funding to the domestic economy while keeping domestic interest rates under control to cope with positive productivity shocks.

Keywords: Foreign Reserves, Capital Controls, Financial Frictions, Capital Formation, Productivity Growth

1. INTRODUCTION

Since the beginning of the twenty-first century, the fast accumulation of international reserves in emerging market economies and developing countries has driven the world's total international reserves to an unprecedentedly high level. This recent phenomenon has reignited the debate on the reasons motivating the demand for reserve assets among academics and policy makers.

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Inspired by the situation in China, I propose in this paper a theory of foreign reserve accumulation in fast-growing emerging economies. The focal point of the theory resides in the interaction between productivity growth and financial frictions, two features commonly observed in emerging market economies. Positive productivity shocks induce the private sector to invest in capital, whereas financial frictions constrain the private sector's borrowing ability. In this context, domestic capital formation needs to rely on firms' retained earnings. In order to push capital formation to its first-best level—defined as the steady state level without financial frictions—the central bank intervenes by providing the private sector with domestic assets, which are in turn financed by the central bank's investment in foreign reserves. Foreign reserve accumulation is thus motivated by a strong demand for domestic liquid assets, especially when the domestic financial market lacks alternative investment opportunities to absorb the central bank's bond proceeds. By comparing this with a situation of financial autarky, it is shown that the central bank's intervention by channeling external funding to the domestic economy relaxes the credit constraint and raises the domestic interest rate. Altogether, this generates higher retained earnings for the private sector and accelerates domestic capital formation to reach the first-best level.

Using a Ramsey problem, this paper goes one step further to examine conditions under which the central bank's reserve policy is optimal in terms of social welfare. By comparison with a financially open economy, an economy where only the central bank can get access to international financial markets, whereas private capital flows are controlled, is proved to raise social welfare provided there are binding financial constraints. The reason is that with foreign reserve accumulation and capital controls, the central bank can not only channel as much external funding as in a financially open economy—the central bank is merely a financial intermediary between the domestic economy and the rest of the world—but also has the domestic interest rate under control. As a result, it can increase it to encourage domestic firms to save more facing positive productivity shocks.

This paper contributes to a long line of literature on motives for international reserve accumulation. Several different motives have been identified.[1] My paper complements the strand of the literature that argues that foreign reserves can be accumulated because of domestic financial frictions. Song et al. (2011), Wen (2011), and Bacchetta and Benhima (2012) have studied this relationship in a standard open economy setting. They all document that in an open economy, domestic credit frictions generate a wedge between domestic savings and investment and thus lead to a structural surplus of the balance of payments and capital outflows.[2] However, these models only consider the open economy, where official foreign reserves held by a country's monetary authorities and private foreign assets cannot be discriminated. One cannot analyze the central bank's reserve policy per se. By introducing capital controls,[3] my model focuses on the central bank's reserve assets instead of the overall position of foreign assets in the economy. Moreover, my paper argues that it is through domestic public bond provision that the central bank, as a financial intermediary, reduces the wedge between domestic savings

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and investment and transfers external financing into the domestic economy. This is also a missing aspect in the existing literature.

With respect to a joint analysis of foreign reserve accumulation and capital controls, this paper is directly comparable to Bacchetta et al. (2013), but differs in several aspects. First, I nest foreign reserve accumulation in a growth model in order to examine the relationship between reserve holding and economic growth. Second, whereas Bacchetta et al. (2013) present an endowment economy, I focus on the contribution of reserves to domestic capital formation, driver of economic catch-up in emerging market economies. The introduction of capital is crucial for two reasons: it enables me to examine production efficiency gains instead of redistributive effects and consumption smoothing gains in the welfare analysis; and the introduction of capital formation makes the model more relevant to fast-growing countries, such as China. The growth in these countries is largely driven by positive technology shocks and resultant capital accumulation [see Nelson and Pack (1999), Bond et al. (2010), and Ahuja and Nabar (2012)].[4]

The theory that I develop is also related to the seminal contribution of Woodford (1990), who argues that issuing public bonds promotes domestic capital investment and is welfare-improving when the private sector faces borrowing constraints. My paper can be regarded as an extension of Woodford's framework in an open-economy context with possibilities of imposing capital controls; it explains how official foreign reserves can be complementary to domestic bonds in a way that eases domestic financial frictions.

This article yields three sets of interesting policy implications. First, foreign reserve accumulation is a "transition" phenomenon; it is driven by the constrained demand for domestic borrowing due to financial frictions in the context of positive productivity shocks. Second, the model argues in favor of a temporary and timely use of capital controls jointly with the reserve policy; the combined use of these two instruments generates higher welfare during economic transition than in a financially open economy despite the same long-run steady state being reached in both policy regimes. Third, the welfare gains from the joint use of reserve accumulation and capital controls diminish with financial development when the credit constraints become less binding. Therefore, capital controls need to be used in a temporary manner, and their use should not hinder any structural reforms in the financial market.

This paper is organized as follows. Section 2 describes the model setting. Section 3 analyzes reserve accumulation and capital formation in a decentralized economy. Section 4 introduces the optimal policy of the central bank and presents numerical results. Section 5 concludes. A Technical Appendix available in the working paper version [Cheng (2013)] contains the formal proofs.

2. MODEL SETTING

The model that I develop is inspired by that of Bacchetta and Benhima (2012), to which I explicitly add a central bank.[5]

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TABLE 1. Policy regimes

		Policy instruments	
Policy regime	Characteristics	Foreign assets	Interest rate
Financial autarky	No external financing	$B^* = 0$	$r \in \Re^+$
Open economy	Financial liberalization	$B^* \in \Re^+$	$r = r^*$
Semi-open economy	Controls on private flows	$B^* \in \Re^+$	$r \in \Re^+$

The benchmark economy is, however, different from a standard small open economy setting, because capital controls can be imposed by the central bank. Indeed, the central bank can put the model economy in one of three policy regimes: financial autarky, where no capital flows are allowed; a fully open economy, where both the public and private sectors get access to international financial markets; a semi-open economy à la Bacchetta et al. (2013), where only the central bank has access to external financing, and private capital flows are controlled. The central bank can choose the appropriate policy regime through two key variables, foreign assets B^* and domestic interest rate r, as Table 1 illustrates.

2.1. The Private Sector

The private sector in this paper is composed of two symmetric family businesses. Each of them is made up of a continuum of individuals of measure one. Family members in each family business are either workers or entrepreneurs. Within the family business, the worker provides the labor force to the entrepreneur, who in turn pays the worker at the marginal product of labor. Importantly, I assume that the family business pools together the incomes of both family members and optimally makes consumption and investment decisions at the family level.[6] This is a parsimonious way to model households and firms all combined. The advantage of doing so is twofold: it simplifies the program of the private sector and renders the Ramsey problem neater; it also allows both the worker and the entrepreneur to save and to contribute to physical capital investment, in contrast to Bacchetta and Benhima (2012), where only the corporate sector is allowed to save (as the worker in their model is "hand-to-month" and consumes all the labor income every period).

I assume that each family business is infinitely lived and capital is invested every two periods. As a result, any family produces in one period and invests in the other and so on and so forth; that is, each of the two families changes its status every two periods, alternating between a "producing-saving" period (denoted S) and an "investing-borrowing" period (denoted I). The assumption of two symmetric family businesses is to guarantee that in each period there is always one family in the producing-saving stage and one in the investing-borrowing stage, so that there is always an (investing-borrowing) family that faces the borrowing constraint.

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Family businesses' program. As the family businesses are symmetric, it is sufficient to look at the program of one of them. Let us consider the family that starts at time t in the producing-saving period. It faces a standard intertemporal utility function with a discount factor β:

$$\sum_{t=0}^{\infty} \beta^t \left[U(c_t^S) + \beta U(c_{t+1}^I) \right]. \tag{1}$$

It has the following alternating budget constraints every two periods:

$$\text{At } t\text{: } F(A_t, K_t, N_t) - r_t L_t = c_t^S + S_{t+1} + \frac{T_t}{2}, \tag{2}$$

$$\text{At } t+1\text{: } r_{t+1} S_{t+1} + L_{t+2} = c_{t+1}^I + K_{t+2} + \frac{T_{t+1}}{2}. \tag{3}$$

The family business that starts with the investing-producing period at time t has similar budget constraints: at time t, $r_t S_t + L_{t+1} = c_t^I + K_{t+1} + T_t/2$; at time $t+1$, $F(A_{t+1}, K_{t+1}, N_{t+1}) - r_{t+1} L_{t+1} = c_{t+1}^S + S_{t+2} + T_{t+1}/2$.

From (2) and (3), a typical family business in its producing-saving period harvests an output $F(A_t, K_t, N_t)$ (produced with inputs K_t and N_t chosen a period earlier) and makes the decision between current consumption c_t^S and savings S_{t+1}. The willingness to save is explained by the fact that the output is only harvested every two periods. That is, at $t+1$ the family will be in its investing-borrowing period and will rely on retained earnings $r_{t+1} S_{t+1}$ as well as domestic borrowing L_{t+2} to invest in physical capital K_{t+2} and to consume c_{t+1}^I. If the producing-saving family is able to save, it is because the other symmetric family is in the investing-borrowing period and has demands for borrowing (or because additional saving instruments, such as central bank bonds or foreign assets, are available).[7] r_t denotes the sequence of the domestic *gross* interest rates ($r_t > 1$, for all t). T_t denotes lump-sum taxes (transfers) to (from) an implicit government.

The production function $F(A_t, K_t, N_t)$ is a standard neoclassical production function: increasing in all arguments, concave, and homogeneous of degree one. $F_{K,t}$ and $F_{N,t}$ denote the marginal product of capital and that of labor, respectively. A_t stands for a production technology, which is the only source of shocks in the model. The wage payment does not appear in the preceding budget constraints. This is because the wage payment between the worker and the entrepreneur is carried out internally with $w_t = F_{N,t}$, whereas consumption and investment decisions are made by the head of the family at the family level. It is further assumed that the labor supply is inelastic with $N_t = 1$.

Credit constraint and demand for liquid assets. Most importantly, there is a credit constraint facing the family in its investing-borrowing period:

$$L_{t+1} \leq \frac{\psi F(A_{t+1}, K_{t+1})}{r_{t+1}}. \tag{4}$$

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The maximum amount of loans that an investing family can get is conditional on the discounted value of its next-period output, and thus negatively correlated with the domestic interest rate and positively related to the production technology and to the contemporaneous capital investment. $\psi \in [0, 1]$ denotes the tightness of the credit constraint. The smaller the value of ψ, the tighter the constraint.[8]

Whenever the credit constraint is binding, the demand for domestic borrowing is reduced, generating a wedge between savings and borrowing, namely $S_{t+1} - L_{t+1} > 0$. In equilibrium, this leads either to a lower supply of savings and a repressed domestic interest rate—as savings S_{t+1} are pinned down by the constrained borrowing L_{t+1}—or calls for supplementary liquid assets for saving.

The demand for supplementary liquid assets is thus motivated in this paper by the interaction between a fast productivity growth that generates strong incentives to invest and a borrowing constraint that confines both domestic savings and borrowing at a suboptimal level. The motive of the demand for liquid assets is thus different from that in Bacchetta and Benhima (2012), where the liquidity demand is induced by the need to pay the labor force in advance.

Finally, it is assumed that the credit constraint is institutional and cannot be removed in the short run. It is very common to observe obstacles to domestic financing in various emerging and developing countries: direct lending is costly, banks have preference biases in selecting firms to which they grant loans, etc. For example, in China, households have a high level of savings that they are willing to lend to firms in need but fail to do so short of a developed financial market [see Chamon and Prasad (2010)]. In addition, being mostly state-owned, commercial banks in China prefer (and sometimes are obliged) to lend to state-owned enterprises; domestic private firms, although more productive, are unable to get enough loans from commercial banks [see Song et al. (2011)]. To remove the credit frictions, many structural reforms[9] need to be implemented, and this takes time.

2.2. The Central Bank

The central bank issues domestic saving bonds, B_{t+1}, which aim at filling the gap between domestic savings and borrowing. Because of the limited scope of the domestic financial market, the central bank then invests domestic bond proceeds in foreign assets, B^*_{t+1}. The central bank's flow budget constraint is described as follows:

$$r^*_t B^*_t + B_{t+1} + T_t = r_t B_t + B^*_{t+1}. \tag{5}$$

r^*_t is the world interest rate; it is assumed that the world interest rate is constant and equals the inverse of the discount factor β, namely $r^*\beta = 1$ (assuming the same time preference in the domestic economy and abroad). T_t is a lump-sum transfer *from* the government, which taxes households to pay this transfer (this can be a transfer *to* the government as well if $T < 0$). To focus on the central bank's policy, it is assumed that the transfer from (to) the government is exogenous,

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used only to balance the central bank's flow budget constraint each period; it captures the financial gains or losses from the central bank's investment, which are transferred to the government, as the latter can be regarded as the central bank's stakeholder.

The supply of liquid bonds by the central bank is determined by the demand on the domestic market (difference between domestic savings and borrowing):

$$\underbrace{B_{t+1}}_{\text{supply of liquid bonds}} = \underbrace{S_{t+1} - L_{t+1}}_{\text{demand for liquid bonds}} . \tag{6}$$

In a financially open economy, B^* and B are perfect substitutes; the producing-saving family is indifferent between investing in domestic public bonds or foreign assets.[10] In a semi-open economy, namely one with controls on private capital flows, the central bank plays the role of financial intermediary between the domestic economy and external financial markets. Public bonds and foreign assets are thus not perfect substitutes for the private sector. I will show in Section 4 the similarities and differences between these two policy regimes in terms of social welfare.

Central bank's purchases of foreign reserves. The use of public debt, e.g., government or central bank bonds, has proved to be welfare-improving in the presence of market frictions, as Woodford (1990) demonstrates. In this paper, I argue that to provide public liquid bonds the central bank needs to invest abroad. One reason is that in a financially underdeveloped economy, domestic assets that can absorb the central bank's bond proceeds are scarce. This assumption is plausible if one looks at the features of the domestic financial market in China: domestic private bond and equity markets are dwarfed by the large public bond issuance. Another reason is that foreign assets generate higher returns than domestic assets, as the credit constraint drives down the domestic equilibrium interest rate. Figure 1 illustrates the gap between the interest rate on Chinese central bank bills and that on U.S. Treasury bills from 2003 (when data on the interest rates of Chinese central bank bills started to be available) to the onset of the global financial crisis in 2008. It is observed that during this period, which corresponds to a period of fast reserve accumulation, China paid lower interest rates on its central bank bills than that earned on its investment in U.S. Treasury bills. Furthermore, the job of liquidity provision cannot be undertaken by the government, as government financing is usually more closely regulated by law than central bank bonds.

In sum, foreign reserve accumulation is motivated by a strong demand for domestic liquid assets in an economy facing a rapid productivity growth rate and an underdeveloped domestic financial market.

To close the model, the aggregate budget constraint is presented. Output produced by the family in its producing-saving period is consumed by both types of family, invested in capital, and used to buy foreign assets:

$$F(A_t, K_t) = c_t^S + c_t^I + K_{t+1} - r_t^* B_t^* + B_{t+1}^*. \tag{7}$$

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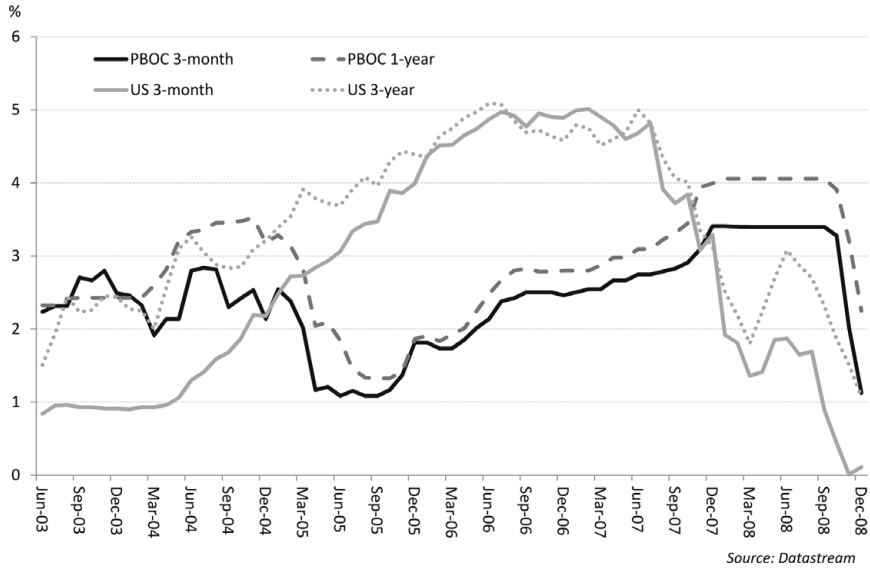


FIGURE 1. Interest rates in China and in the United States.

3. COMPETITIVE MARKET EQUILIBRIUM

In this section, I present fundamental features of the model in a competitive market equilibrium and emphasize how the credit constraint motivates either a financial liberalization (open economy) or an active intervention of the central bank (semi-open economy). An analysis of domestic capital formation will also be given a special attention. In order to derive analytical results, log-utility and a Cobb–Douglas production function are used henceforth, namely $U(c_t^i) = \log(c_t^i), i \in (S, I)$ and $F(K_t, A_t) = K_t^{\alpha} A_t^{1-\alpha}$ [11]. For simplicity, I assume that $T = 0$, that is, the central bank balances its balance sheet with domestic bonds and foreign assets every period.

DEFINITION 1. *A perfect foresight market equilibrium in a decentralized economy is a sequence of allocation* $\{c_t^S, c_t^I, K_{t+1}, S_{t+1}, L_{t+1}\}$*, for a given sequence of price* $\{r_t\}$*, policy set* $\{B_t^*, B_t, T_t\}$*, and initial conditions* $\{K_0, L_0, S_0, B_0, B_0^*, T_0\}$*, such that for all* $t > 0$*: (1) the utility function* (1) *is maximized subject to the family business' budget constraints* (2) *and* (3)*; (2) the borrowing constraint* (4) *is verified; and (3) the central bank's budget constraint* (5)*, financial and good market clearing conditions* (6) *and* (7) *are all respected.*

The first-order conditions for the family business in its producing-saving stage at time t are presented in the following (the first-order conditions of the other family can be derived by symmetry):

$$(1 + \psi\lambda_t)F_{K,t} = r_t(1 + \lambda_t), \tag{8}$$

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$$u'(c_t^S) = \beta r_{t+1} u'(c_{t+1}^I), \tag{9}$$

$$u'(c_{t+1}^I) = \beta r_{t+2} u'(c_{t+2}^S)(1 + \lambda_{t+2}). \tag{10}$$

$\lambda_t u'(c_t^S)$ denotes the Lagrange multiplier associated with the credit constraint at time t. (8) tells us that the marginal product of capital is equal to the cost of capital r_t augmented by a coefficient $\frac{1+\lambda_t}{1+\psi\lambda_t}$, which is related to the credit constraint. (9) and (10) are Euler equations. The Euler equation (10), which relates the marginal utility of consumption of an investing family to that of the same family in its producing-saving stage a period later, clearly depends on the credit constraint, λ_{t+2}.

According to the Kuhn–Tucker theorem, the Lagrange multiplier with respect to the credit constraint verifies $\lambda_t u'(c_t^S)[r_t L_t - \psi F(A_t, K_t)] = 0$. Therefore, $r_t L_t = \psi F(A_t, K_t)$ if the credit constraint is binding or $\lambda_t = 0$ if the constraint is unbinding.

Using the log-utility and equations (2) and (3), the consumption can be expressed as a share of the wealth: $c_t^S = (1 - \beta)[F(A_t, K_t) - r_t L_t]$ and $c_{t+1}^I = (1 - \beta) r_{t+1} S_{t+1}$.

This gives

$$S_{t+1} = \beta\Big[F(A_t, K_t) - r_t L_t\Big], \tag{11}$$

$$K_{t+2} - L_{t+2} = \beta r_{t+1} S_{t+1}. \tag{12}$$

3.1. Uniqueness in the Steady State

The steady state is uniquely determined when the credit constraint is binding. This result is important in analyzing capital formation and other features of the model. For this purpose, I normalize all endogenous variables by the output $F(A_t, K_t)$; namely, I define $b^* = B^*/F(A, K)$, $b = B/F(A, K)$, and $\tau = T/F(A, K)$.

The central bank's budget constraint (5) becomes

$$(r^* - 1)b^* + \tau = (r - 1)b. \tag{13}$$

Given international and domestic interest rates as well as the level of government transfer, one can observe from (13) that if the central bank wants to provide liquid assets in the domestic economy, it can achieve this objective by purchasing foreign reserves.

PROPOSITION 1. *Considering the simplest case, where* $\tau = 0$ *(central bank does not have financial gains/losses in the long run), the financially constrained steady state is uniquely determined if* $0 < b < \beta(1 - 2\psi)$.

Proposition 1 implies that the credit constraint is not binding when $b \geq \beta(1 - 2\psi)$; the central bank can achieve this goal by raising b^*. When the credit constraint is nonbinding, the domestic interest rate is equal to the world interest rate

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$r = r^* = 1/\beta$; when the credit constraint is binding, the domestic interest rate is repressed and lower than its international counterpart. Moreover, when the central bank provides liquid bonds that are scarce in the economy, it lowers the price of the liquid bonds and pushes the domestic interest rate up to the world interest rate level. r is indeed increasing in b: $r = \frac{\psi}{\beta(1-\psi)-b}$.

We can further look at the steady state in different policy regimes.

Financial autarky. In a closed economy where $B^* = 0$, if $\psi \geq 1/2$, the credit constraint does not bind in the steady state. In this case, $\beta r = 1$; namely, the domestic interest rate is equal to the world interest rate. $K = A(\alpha\beta)^{1/(1-\alpha)}$, so the capital stock achieves its first-best level (i.e., the long-run steady state with a nonbinding credit constraint). Consumption is perfectly smoothed; namely, the consumption in the saving stage and that in the investing stage are equalized: $c^S = c^I$.

If $\psi < 1/2$, the credit constraint binds in the steady state. The Lagrange multiplier associated with the credit constraint is thus positive, $\lambda = 1/\beta^2 r^2 - 1 > 0$. The domestic interest rate is lower than the world interest rate, namely, $\beta r = \frac{\psi}{1-\psi} < 1$. The capital stock, $K = A\{\alpha[(1-\psi)\beta^2 r + \frac{\psi}{r}]\}^{1/(1-\alpha)}$, cannot achieve the first-best level. As for consumption, that of the investing stage is always smaller than that of the saving stage, $\frac{c^I}{c^S} = \frac{\psi}{1-\psi} < 1$.

In fact, in a financial autarky, with positive productivity shocks, the more capital invested the better. There is thus a strong demand for capital investment. However, the investing family is financially constrained and the aggregate economy does not have sufficient resources to finance the investment, as no external financing is available. The left panel in Figure 2 shows that in the case of a decrease in ψ, the credit constraint becomes more binding and the demand for domestic assets increases while the supply remains fixed (because of the financial autarky). This results in a sharp decrease in the domestic interest rate. This is undesirable both for capital investment and for domestic consumption.

Open economy. One big difference here from financial autarky is that the economy has access to external financing. This results in equalization between the domestic interest rate and the world interest rate, $r = r^* = 1/\beta$. There is an unlimited supply of external financing. In this case, the credit constraint is never binding, leading to $b = b^* = \beta(1-2\psi)$. In an open economy, both the central bank and the private sector get access to the international financial market, and therefore central bank bonds and foreign assets are perfect substitutes. The saving family can choose to save with either financial asset. In the aggregate, there are sufficient assets with which the producing-saving family can save at the world interest rate r^* (see the middle panel in Figure 2). Capital formation and consumption all reach the first-best level. Clearly, in the steady state, the open economy dominates financial autarky.

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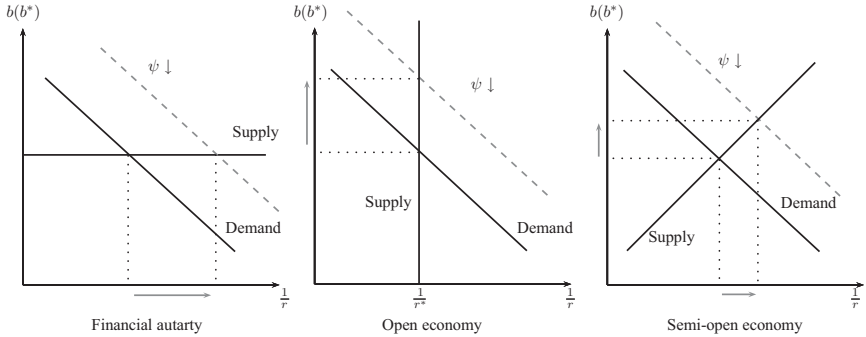


FIGURE 2. Effects of a tightening of the credit constraint.

Semi-open economy. Another possibility for amending the shortcomings of financial autarky is to allow the central bank to provide extra liquid assets. The semi-open economy is indeed a nested situation of financial autarky and the open economy. In the steady state, the central bank can mimic the open economy by purchasing the same amount of foreign assets as in the open economy case. The only difference is that central bank bonds and foreign assets are no longer perfect substitutes, as the private sector is forced to buy central bank bonds without the possibility of access to foreign financing. A supply of central bank bonds also reduces the price of liquid assets (previously overpriced), raising the domestic interest rate (see the right panel in Figure 2). In the steady state, a semi-open economy can do as well as an open economy.

3.2. Capital Formation

How does the capital stock evolve over time? From (11) and (12), capital accumulation that is consistent with optimal consumption in a financially constrained economy satisfies

$$K_{t+2} = \underbrace{\beta r_{t+1} S_{t+1}}_{\text{retained earnings}} + \underbrace{L_{t+2}}_{\text{loans}}$$

$$= \beta^2 r_{t+1}(1-\psi)F(A_t, K_t) + \frac{\psi F(A_{t+2}, K_{t+2})}{r_{t+2}}. \tag{14}$$

Notice that retained earnings and loans are affected by the interest rate in opposite ways. An increase in the domestic interest rate raises the retained earnings of the saving family (revenue effect) but reduces the loans that the same family may make next period during its investing period (borrowing effect). Whether capital stock increases or decreases depends on which effect dominates.

A feedback loop effect through capital investment can be observed in (14). Namely, more capital invested provides stronger collateral (as the capital enters into the production function), allowing the investing family to borrow more during

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the investing stage and relaxing the credit constraint. This pushes up capital investment further. For example, an initial positive shock on retained earnings (either an increase in r_{t+1} or an increase in the initial capital stock K_t) will lead to an increase in capital formation at $t+2$ (through the revenue effect), which in turn drives loans up (through the feedback loop). Capital formation K_{t+2} further increases, generating a virtuous cycle.

To better understand the impact of the interest rate on domestic capital formation,

$$F_K = \frac{r}{(\beta r)^2 + \psi[1-(\beta r)^2]} \tag{15}$$

can be derived in the steady state using (8)–(10). Three distinct effects on capital stock can be identified: (1) opportunity cost of capital, (2) revenue effect, $(\beta r)^2 = \frac{1}{1+\lambda}$, and (3) borrowing effect, $\psi[1-(\beta r)^2]$.

The first effect, the opportunity cost of capital, is standard: the higher r, the higher the cost of investing in capital stock, the less capital is demanded. The other two effects are specific to this model.

The second term $(\beta r)^2$ is related to families' saving revenues. As families are occasionally credit-constrained, they have incentives to rely on retained earnings to invest in capital. As the retained earnings are increasing in the interest rate, the revenue effect has a positive impact on capital stock. Notice that the square appears because the capital is invested every two periods. In an extreme case, when $\psi = 0$ (i.e., no borrowing is possible), families rely entirely on retained earnings for capital investment. The revenue effect clearly dominates the opportunity cost. As a result, a larger supply of liquid bonds leads to a higher domestic interest rate and higher retained earnings. This unambiguously increases the capital stock.

The third effect stems from the fact that the loans that an investing family can ask for are conditional on the discounted value of future production. An increase in r lowers the borrowing capacity of the investing family, as it reduces the discounted value of the collateral. The interest rate thus has a negative borrowing effect on capital stock.

PROPOSITION 2. *Capital stock represents a U-shaped curve as a function of βr in the steady state. Purchasing foreign reserves, which leads to a higher supply of domestic liquid assets and thus a higher interest rate, increase capital stock and output production in the economy.*

From Figure 3, the capital stock achieves the first-best level if $\beta r = 1$ (i.e., in an open economy steady state) or $\beta r = \frac{\psi}{1-\psi}$. However, the latter case is ruled out by the uniqueness of the binding steady state [see Cheng (2013) for a formal proof].

When $\frac{\psi}{1-\psi} < \beta r \leq \sqrt{\frac{\psi}{1-\psi}}$, the curve is decreasing. That is, when the financial constraint is stringent, the initial domestic interest rate is very low, and any increase in the interest rate decreases the value of the collateral, leading to a decrease in borrowing. The initial domestic savings are also very low; short of saving

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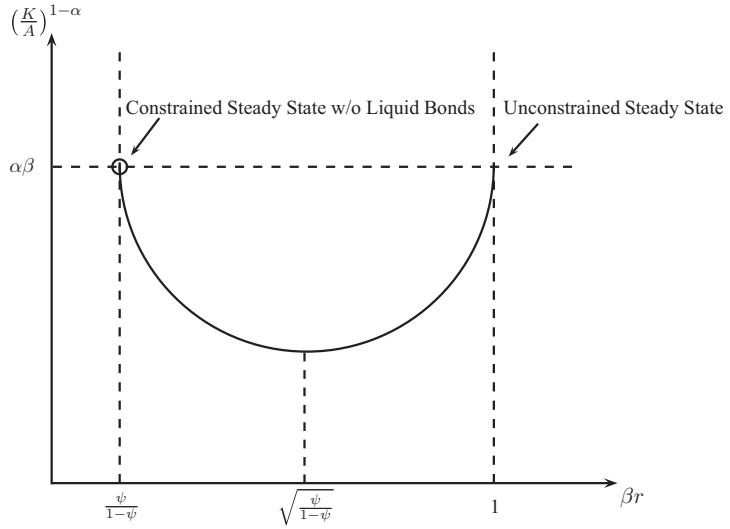


FIGURE 3. U-shaped capital formation.

instruments, an increase in retained earnings (due to a rise of interest rate) cannot offset the decrease in borrowing. Therefore, in this part of the curve, the borrowing effect of the interest rate dominates the revenue effect, leading to a decrease in capital stock. The initial steady state (before the realization of any technology shock) can only be located on the lower part of this decreasing curve, as βr is proved to be strictly higher than $\frac{\psi}{1-\psi}$.

When $\sqrt{\frac{\psi}{1-\psi}} < \beta r \leq 1$, the curve is increasing. This is because when the central bank provides more liquid assets, families save more. The supply of central bank bonds also decreases the price of previously overpriced liquid assets. As a result, families' retained earnings increase because of both a quantity effect (more saving instruments) and a price effect (higher interest rate). The retained earnings are used for capital investment a period later, when the family faces investment opportunities. The revenue effect thus dominates the borrowing effect in this part of the curve.

4. THE CENTRAL BANK'S OPTIMAL POLICY

Section 3 showed that an open economy and a semi-open economy achieve the same unconstrained steady state in the long run. Based on a Ramsey problem, I demonstrate in this section how the welfare effects can be different in these two policy regimes during economic transition. This is the third important result of this paper: the economy where the central bank imposes capital controls and accumulates foreign reserves (semi-open economy) dominates the financially open economy on the convergence path.[12] This is because the incentives to invest are

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particularly strong during a fast-growing transition; in addition to the supply of sufficient funding to domestic firms, the central bank can effectively adjust the domestic interest rate to cope with unanticipated productivity shocks should private capital flows be controlled.

4.1. Ramsey Problem

The central bank optimizes the consumption of the two contemporaneous symmetric families according to the following objective function:

$$\max_{\{S_{t+1},L_{t+1},K_{t+1},c_t^S,c_t^I,B_{t+1}^*,r_{t+1}\}} \sum_{t=0}^{\infty} \beta^t \Big[u(c_t^S) + u(c_t^I)\Big]. \tag{16}$$

DEFINITION 2 (Ramsey problem). *The central bank's optimal policy consists of choosing a sequence of policy variables* $\{B_{t+1}^*, B_{t+1}, r_{t+1}\}$ *and a sequence of endogenous private sector variables* $\{c_t^S, c_t^I, K_{t+1}, L_{t+1}, S_{t+1}\}$ *for all* $t > 0$ *such that (1) the corresponding competitive equilibrium allocation* (8)–(10) *maximizes the welfare function* (16)*; (2) individual families' budget and credit constraints,* (2)–(4)*, are verified; (3) the central bank's budget constraint* (5)*, bond market clearing* (6)*, and resource constraint* (7) *are all respected.*

The solution to the Ramsey problem follows the "primal approach" described by Erosa and Gervais (2001).

The full Ramsey problem is as follows:

$$\begin{aligned}
\max_{\{S_{t+1},L_{t+1},K_{t+1},c_t^S,c_t^I,B_{t+1}^*,r_{t+1}\}} \sum_{t=0}^{\infty} \beta^t \Bigg\{ & u(c_t^S) + u(c_t^I) \\
& + \eta_t^S \Big[F(A_t, K_t) - r_t L_t - c_t^S - S_{t+1} - \frac{T_t}{2}\Big] \\
& + \eta_t^I \Big[r_t S_t + L_{t+1} - c_t^I - K_{t+1} - \frac{T_t}{2}\Big] \\
& + \eta_t^G \Big[F(A_t, K_t) - c_t^S - c_t^I - K_{t+1} - B_{t+1}^* + r_t^* B_t^*\Big] \\
& + \theta_t^S \Big[\frac{1}{c_t^S} - \beta r_{t+1} \frac{1}{c_{t+1}^I}\Big] \\
& + \theta_t^I \Big[\frac{1}{c_t^I} - \beta r_{t+1}(1+\lambda_{t+1}) \frac{1}{c_{t+1}^S}\Big] \\
& + \rho_t \Big[(1+\psi\lambda_t) F_{K,t} - r_t(1+\lambda_t)\Big] \\
& + \Lambda_t \Big[\psi F(A_t, K_t) - r_t L_t\Big] \Bigg\}.
\end{aligned}$$

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TABLE 2. Calibrated parameters

Parameter	Description	Value
α	Share of capital in the production	0.50
β	Discount factor	0.95
ψ	Credit constraint tightness	0.12
ϵ	Initial shock on productivity growth	0.10
σ	Persistence of productivity shock	0.50

As presented in Section 2, the way to model capital controls in this paper is through two key variables, B^*_{t+1} and r_{t+1}. In a semi-open economy with capital controls, one needs to derive the first-order conditions with respect to both B^*_{t+1} and r_{t+1}, as they are all policy variables controlled by the central bank. In an open economy, however, only the first-order condition with respect to B^*_{t+1} is derived, as the central bank cannot set the domestic interest rate, which is always equal to the world interest rate. As I will show in the following section, the superiority of the semi-open economy over the open economy stems precisely from the central bank's ability to manipulate the domestic interest rate, r_{t+1}.

4.2. Numerical Results

This section provides direct insight into the superiority of the semi-open economy over an open economy using numerical simulations.[13]

Calibration. The productivity growth is assumed to follow an AR(1) process, $A_t = (1 + g_t)A_{t-1}$ and the growth rate of the productivity is determined by $g_t = \sigma g_{t-1} + \epsilon$. σ stands for the persistence of the productivity growth, which is less than 1, and ϵ is an unanticipated shock. I simulate the model by setting a positive shock of 10% on the productivity growth rate at the beginning of period 1. The productivity process and the shock are used to mimic the fast economic catch-up in emerging economies.

The discount factor β is calibrated to match the average yields of one-year U.S. Treasury bills.[14] This gives $\beta = 1/r^* = 1/1.05 = 0.95$. The capital share is set to $\alpha = 0.5$, consistent with Bai et al. (2006) and also used by Song et al. (2011), which is the most recent and influential quantitative work on Chinese economic growth. I choose the value of the key parameter ψ, tightness of the credit constraint, to match the savings-to-output ratio in the initial steady state of simulations with China's average gross saving rate (as a percentage of the national income).[15] This gives $\psi = 0.12$. A summary of parameter values can be found in Table 2.

Notice that because of the parsimony of the model, the numerical results that I present in the following only aim at illustrating the qualitative results derived from the model.

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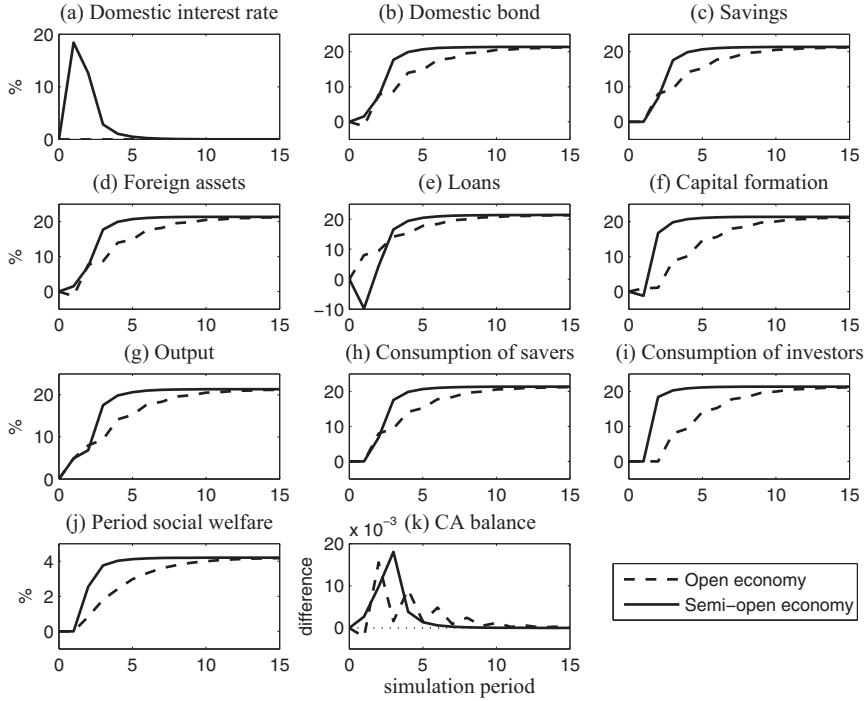


FIGURE 4. Impulse responses. The figure shows the percentage deviation from the initial steady state (except for current account balance) in a semi-open economy (solid lines) and in an open economy (dashed lines) for the impulse responses to a positive productivity shock of 10% at the beginning of period 1.

Superiority of the semi-open economy during economic transition. Figure 4 presents the impulse responses from the numerical exercise. Unless otherwise noted (i.e., for the current account balance, which is expressed in absolute change), all impulse responses are expressed in terms of the percentage deviation from the initial steady state (period 0). The solid lines represent the results in a semi-open economy, whereas the dashed lines represent that in an open economy.

It has been analytically demonstrated in Section 3 that a semi-open economy and an open economy can both achieve the long-run steady state with a nonbinding credit constraint (first-best situation). In fact, Figure 4 shows that all variables achieve the same final steady state regardless of the policy regime. Recall that a semi-open economy is an economy where *only* the central bank gets access to foreign financial markets, whereas private capital flows are strictly controlled; an open economy is, in contrast, an economy with a fully liberalized capital account. In the steady state, accumulating foreign reserves while keeping the capital account closed does not allow the central bank to do better than in a fully open economy. This is because the central bank in the steady state accumulates sufficient

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foreign assets so that the domestic interest rate catches up with the world interest rate.

However, during economic transition, especially when the productivity growth suddenly becomes higher, the combined use of foreign reserves and capital controls allows faster convergence to the final steady state than in a fully open economy (the solid lines are in general higher than the dashed lines during transition). This is precisely due to the autonomy of the central bank in setting the domestic interest rate in a semi-open economy. Facing the same productivity shock at the beginning of period 1, the central bank immediately raises the domestic interest rate in a semi-open economy, whereas the interest rate is fixed in an open economy [Panel (a)]. To achieve this, the central bank provides more saving instruments [Panel (b)], with which the producing-saving family can save to overcome the credit constraint. The private sector indeed has incentives to save more in a semi-open economy [Panel (c)]. On one hand, this is because it is financially more interesting for the private sector to save with a higher interest rate. On the other hand, a positive productivity shock triggers a strong demand for capital investment as the marginal product of capital rises; because of future binding credit constraints, the private sector can increase investment only by saving more.

The pace of reserve accumulation accelerates accordingly [Panel (d)] as the central bank invests its bond proceeds abroad. Regarding the loans [Panel (e)], in a semi-open economy, the demand for loans first declines with the rise of the domestic interest rate, as a higher interest rate reduces the discounted value of the collateral, making the contemporaneous credit constraint more binding. However, as shown in Section 3.2, there is a positive feedback loop effect with the capital that serves as collateral for borrowing. With an overall increase in domestic capital formation, the demand for loans ultimately increases through a positive collateral effect. From Panel (f), one can indeed observe that in a semi-open economy, capital decreases in the first period because of the decline of loans in response to a rise of the domestic interest rate, but increases afterward at a more rapid pace to reach the steady state, thanks to the higher level of the private sector's saving revenues and to a relaxed credit constraint.

One can see in Panel (g) that output increases steadily to reach a 20% higher new steady state at an accelerated pace in the semi-open economy; so does consumption in both the producing-saving and the investing-borrowing period [Panels (h) and (i)]. Panel (j) presents the deviation from the initial steady state of the period welfare, defined as the sum of the two families' utilities in each period. The social welfare increases faster in a semi-open economy because of accelerated growth of production. Finally, Panel (k) shows that the economy runs a balance-of-payments surplus during the economic transition, as the central bank constantly purchases foreign assets to finance domestic bond issue.

In sum, one can see that in a semi-open economy, the central bank not only can provide sufficient domestic funding by investing in foreign reserves, but also can tackle unanticipated productivity shocks by adjusting the domestic interest

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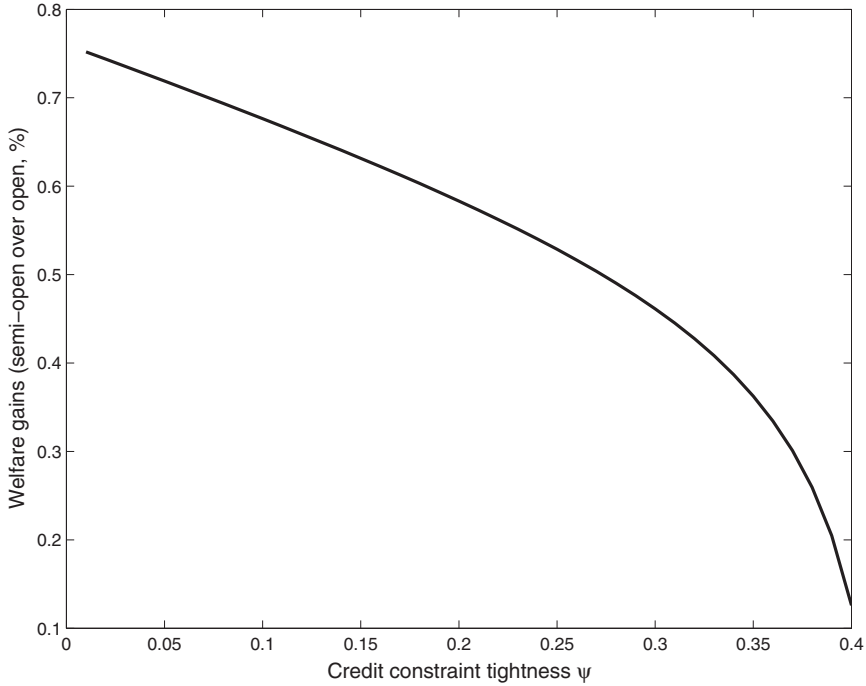


FIGURE 5. Simulation: Welfare gains.

rate. The combined policy of reserve accumulation and capital controls makes the semi-open economy better off and allows it to reach the higher final steady state more rapidly.

Financial frictions and capital controls. How do the welfare gains in a semi-open economy depend on the main assumption of the model, namely a binding credit constraint?

I first calculate the social welfare according to the welfare function (16) separately in an open economy and a semi-open economy, for different values of the credit constraint tightness ψ. Then I calculate the welfare gains in a semi-open economy compared to an open economy and present them as a function of the parameter ψ. The result is shown in Figure 5.

One can observe that the bigger ψ—the less binding the credit constraint—the lower the welfare gains of a semi-open economy over an open economy. Moreover, the closer ψ gets to the threshold value 0.5, the sharper the decline in the welfare gains. This is because when ψ increases and goes close to 0.5, the demand for loans from the investing-borrowing family is close to the nonbinding level and almost absorbs the maximum savings that the producing-saving family is willing to provide. In the extreme case, where there is no more credit constraint, a semi-open economy can do no better than an open economy; the welfare gains associated

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with capital controls and foreign reserve accumulation vanish. Put in another way, in an economy with few financial frictions, liberalizing the capital account is the first-best strategy.

This result sheds light on the temporary character of the benefits from the use of capital controls. In fact, capital controls are welfare-improving and need to be maintained only if there are strong imperfections in the domestic financial market. Once appropriate financial reforms eliminate financial frictions, there is no more reason for imposing capital controls.

5. CONCLUSION

Based on the model presented in this paper, I can partly attribute the rapid accumulation of foreign exchange reserves in fast-growing emerging economies to the joint force of positive productivity shocks and domestic financial market frictions. In fact, facing a rapid economic catch-up, the private sector in these countries has a strong demand for liquid assets to support capital investment. In the absence of a sound financial market with sufficient domestic assets, the central bank has to serve as a financial intermediary to provide domestic liquid assets by investing abroad in foreign exchange reserves if it is short of domestic investment opportunities.

This paper also proves that during the economic transition characterized by positive productivity shocks it is welfare-improving to let the central bank accumulate foreign reserves and supply domestic liquid assets instead of letting the private sector itself hold foreign assets. That is, a combined used of foreign reserves and capital controls leads to a faster economic transition than in a situation of financial liberalization. This is because when private capital flows are controlled, the central bank can adjust the domestic interest rate to cope with any positive productivity shock, in addition to the supply of sufficient saving instruments. The welfare gains in a semi-open economy with capital controls diminish, however, with the development of the domestic financial market; welfare gains vanish when the domestic credit constraint hardly binds. This suggests that capital controls should only be used when the domestic financial market is underdeveloped. In the long run, a country needs to implement structural reforms and to open its capital account.

There are several possibilities for addressing additional interesting issues related to this paper. For one thing, one may think of making capital controls a continuous variable; Schmitt-Grohe and Uribe (2003) and Bénassy-Quéré et al. (2011) provide a framework for doing so. In this regard, foreign reserve accumulation can be studied in the context of the optimal sequencing between financial reforms and capital account liberalization. Moreover, the current model finds it optimal for the domestic economy to accumulate reserves and set capital controls, it might not be the case if cross-country spillover effects are taken into account. It would be interesting to study the same question in an international context by extending the model into a two-country framework.[16]

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NOTES

1. For a detailed account of the precautionary motive for reserve accumulation, see Aizenman and Lee (2007), Alfaro and Kanczuk (2009), Aizenman and Hutchison (2010), Jeanne and Rancière (2011), Bianchi et al. (2013), Benigno and Fornaro (2012), Calvo et al. (2013), and Bussière et al. (2014). For the mercantilist approach, see Dooley et al. (2003), Korinek and Serven (2010), and Jeanne (2013). For an account of the relationship between reserve accumulation and domestic financial conditions, see Caballero et al. (2008), Dominguez (2010), Obstfeld et al. (2010), Song et al. (2011), Wen (2011), and Bacchetta et al. (2013). Recent empirical papers, such as Delatte and Fouquau (2012), Ghosh et al. (2012), and IEO (2012) shed light on the country-group-specific and time-varying aspects of foreign reserve accumulation.

2. For additional references regarding the relationship between excess savings and a balance-of-payments surplus, see Bénassy-Quéré et al. (2011) and Coeurdacier et al. (2012).

3. Benigno and Fornaro (2012) also look at the imperfect substitutability between public and private flows. Instead of imposing capital controls as this current article does, they choose to impose an external borrowing constraint on private firms. Also, they study different motives for reserve accumulation.

4. Notice that this view challenges somehow the widespread view on Chinese export-led growth. However, one can easily calculate the contribution to Chinese GDP growth. Investment is by far the most important contributor (more than 40% since 2000).

5. More standard models with a representative agent can be found in Korinek (2011), Jeanne (2013), etc.

6. There are other papers that adopt this strategy of modeling a family business (or "representative family") composed of two types of members, such as Merz (1995) or Ljungqvist and Sargent (2007).

7. In the current setting, families lend to each other directly and the banking sector is absent. However, the results that I derive in the subsequent sections will not change even if a competitive banking sector is introduced. Therefore, to keep the model tractable, I decide to leave the financial sector aside.

8. The form of the credit constraint can be micro-founded based on the contract enforcement argument [e.g., Bernanke et al. (1999)].

9. One may especially think of fiscal reforms (reinforcing domestic firms' financial situation), standardization of accounting principles, etc.

10. In this case, it is theoretically equivalent to solve the model by letting families choose their allocation in foreign assets or letting the central bank do it for the sake of the private sector.

11. Log-utility is only required to derive the uniqueness of the constrained steady state. The results do not change with a more general form of the utility function [e.g., constant relative risk aversion (CRRA)].

12. For an empirical account of the joint use of foreign reserves and capital controls, see Aizenman et al. (2011) and Bussière et al. (2014).

13. The simulations are obtained using Dynare 4.3.2; see Adjemian et al. (2011).

14. The average rate of return on one-year U.S. Treasury bills amounts to 5% between 1998 and 2005. This rate can be regarded as a proxy to measure the world interest rate in this paper. Data source: Datastream.

15. This amounts to 42% between 1998 and 2005. Data source: World Bank WDI database.

16. There are a couple of new papers studying the impact of foreign reserves using a two-country model in the context of bilateral relations between China and the United States [e.g., Bonatti and Fracasso (2013)].

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