Hot Money and Serial Financial Crises*

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Abstract

When one region of the world economy experiences a financial crisis, the world-wide availability of investment opportunities declines. As global investors search for new destinations for their capital, other regions will experience inflows of hot money. However, large capital inflows make the recipient countries more vulnerable to future adverse shocks, creating the risk of serial financial crises. This paper develops a formal model of such flows of hot money and the vulnerability to serial financial crises. We analyze the role for macro-prudential policies to lean against the wind of such capital flows so as to offset the externalities that occur during financial crises. Summarizing the results of our model in a simple policy rule, we find that a 1 percentage point increase in a country's capital inflows/GDP ratio warrants a 0.87 percentage point increase in the optimal level of capital inflow taxation.

JEL Codes: F34, E44, G38
Keywords: hot money, financial fragility, serial financial crises, macro-prudential regulation, capital controls, currency wars

1 Introduction

In recent decades, the world economy has experienced serial financial crises that seemed to be linked by a recurrent pattern: one country or sector in the world economy experiences a financial crisis; capital flows out in a panic; investors seek a more attractive destination for their money. In the next destination, capital inflows create a boom that is accompanied by rising indebtedness, rising

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asset prices and booming consumption – for a time. But all too often, these capital inflows are followed by another crisis. Some commentators describe these patterns of capital flows as "hot money" that flows from one sector or country to the next and leaves behind a trail of destruction.

The goal of this paper is to develop a model that captures these phenomena and that analyzes optimal policy responses. In the model, there are multiple borrowing countries that access finance from a group of international investors. Financial relationships are subject to collateral constraints that depend on the value of the asset holdings of borrowers. When a given borrowing country experiences an adverse shock, its financial constraints become binding and borrowers need to cut back on consumption, which leads to financial amplification effects, i.e. an episode of falling asset prices, tightening borrowing constraints and further declining consumption. However, if there is less loan demand, lenders face a shortage of investment opportunities and bid the interest rate below its steady state level. This in turn increases the incentives for other, unconstrained countries to raise their debt burden and expose themselves to greater risk of future financial constraints. This is the sense in which money becomes "hot" – each time one borrower faces a crisis, money flows to the next and increases that borrower's financial fragility, making them vulnerable to "serial financial crises."

It is well-known that individual countries that are prone to financial amplification effects borrow excessively because borrowers do not internalize that their actions increase aggregate financial instability (see e.g. Jeanne and Korinek, 2010). This paper adds a general equilibrium analysis and investigates the externalities of financial crises across countries. We find that excessive borrowing in a given country is particularly prevalent when other countries in the world economy have just experienced a financial crisis so that interest rates are low and the remaining countries experience inflows of "hot money." Under such circumstances, we find that macro-prudential policy measures are especially important.

Specifically, our numerical analysis shows that an adverse shock of a given size that normally leads to a 12% decline in domestic absorption will cause a 14.6% decline in domestic absorption if a country has just experienced inflows of hot money. By imposing a macroprudential tax on capital inflows of close to 2%, these magnitudes can be reduced to 8.8% and 10% respectively. This magnitude of inflow taxation is within the range of policy measures that have recently been enacted by a number of emerging economies. Summarizing the optimal response of macroprudential taxation to flows of hot money in a simple linear policy rule, we find that a 1 percentage point increase in a country's capital inflows/GDP ratio in our model warrants a 0.87 percentage point increase in the optimal level of capital inflow taxation.

1.1 Empirical Motivation

In the following, we document the empirical relationships between movements in world interest rates, capital flows, and the risk of financial crises.

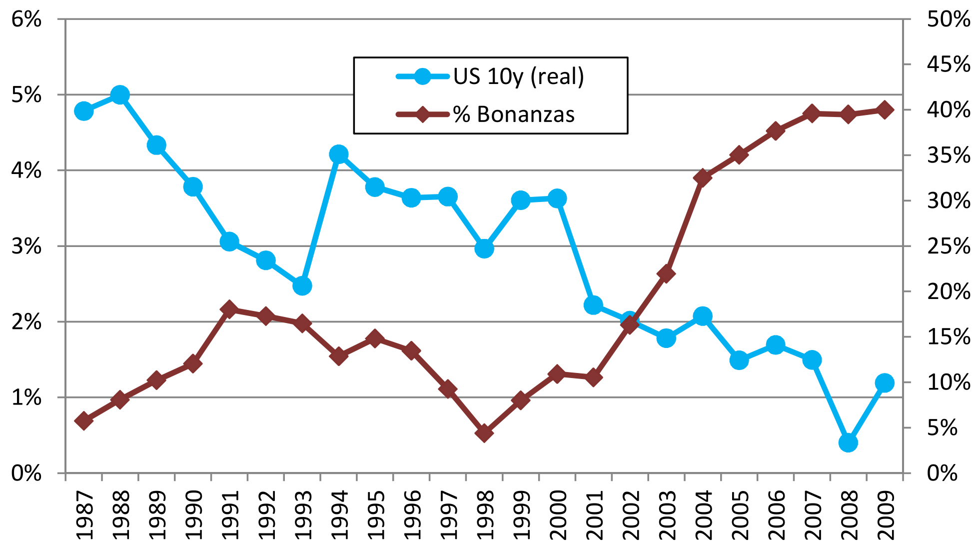

Figure 1: World interest rate and capital flows

Notes: This figure depicts the correlation between world interest rates, as captured by the real yield of ten year US Treasury securities, and the fraction of countries in the world economy that experienced capital flow bonanzas as defined by Reinhart and Reinhart (2008).

Figure 1 illustrates the relationship between world interest rates and the incidence of capital flow bonanzas over the past quarter decade, i.e. the period when most developed countries had abolished their controls on international capital flows. World interest rates are captured by the yield of ten year US Treasury securities deflated by the three-year moving average of US consumer price inflation. The indicator for capital flows reflects the fraction of countries in the world economy which experienced a capital flow bonanza as defined by Reinhart and Reinhart (2008), i.e. a current account in the lowest quintile of realizations.

It can be seen that declining interest rates were generally associated with an increase in the incidence of such bonanzas, most notably in the aftermath of the recession of 1990/91 and in the aftermath of the dot.com bust and the ensuing recession of 2001. The correlation between the two variables is a statistically significant -0.69. On the left side of table 1, we report the results of a Granger causality test between low US interest rates and capital inflow bonanzas in a panel of 176 countries. (Details on the data sources and estimation strategy are provided in appendix A.) It can be seen that lagged US real interest rates significantly Granger-cause capital inflow bonanzas to countries around the world.[1] Reinhart and Reinhart (2008) emphasize that such bonanzas are

[1] We also performed Granger causality tests using alternative measures of interest rates and the results were consistent with those reported in table 1.

strongly associated with booms in asset prices, real estate prices and exchange rates.

	bonanza_t
bonanza_{t-1}	.380***
	(26.2)
US10y_{t-1}	-.016***
	(-5.17)
c	.152***
	(12.9)

	crisis_t
crisis_{t-1}	.043**
	(3.0)
bonanza_{t-1}	.035***
	(3.5)
c	.071***
	(16.5)

Table 1. Granger causality tests

Notes: The table reports Granger causality tests between world interest rates and capital inflow bonanzas (left side) as well as between capital inflow bonanzas and crises (right side). ** and *** indicate significance at the 1% and .1% levels. t-values are reported in parentheses.

Figure 2 illustrates the link from capital flows to crises. We report the percentage of countries that experience capital flow bonanzas as in the previous figure but lag it by two years. The second line captures the fraction of countries in the world economy that experienced a banking crisis, as defined by Reinhart and Reinhart (2008). The two indicators are significantly positively correlated until 2001, with a coefficient of correlation of 0.53. After this period, a "super-bonanza" takes off in which the lag between capital flow bonanzas and crises seems to have lengthened – but the large bonanzas between 2001 and 2007 have certainly played an instrumental role in the ensuing global financial crisis of 2008.

The next figure 3 depicts the probability of a country suffering a crisis conditional on having experienced a capital inflow bonanza t years ago. The dashed lines represent a 95% confidence interval. For comparison, the horizontal line illustrates the unconditional probability of a country in the sample to experience a crisis, which is 5.8%. It can be seen that if a country experiences a capital inflow bonanza, the probability that it suffers a crisis in the ensuing years is significantly elevated, with a maximum of 8.3% two years after the bonanza took place.

On the right side of table 1, we report a Granger causality test for the relationship between capital flow bonanzas and crises. Capital flow bonanzas Granger-cause financial crises at the .1% significance level.[2]

[2] In the reported test, the crisis variable is the union of banking crises as defined by Reinhart and Rogoff (2009) and currency crises as defined by Frankel and Rose (1996). We also performed the tests for each crisis indicator separately and the results were consistent with those reported in the table, though at slightly lower significance levels.

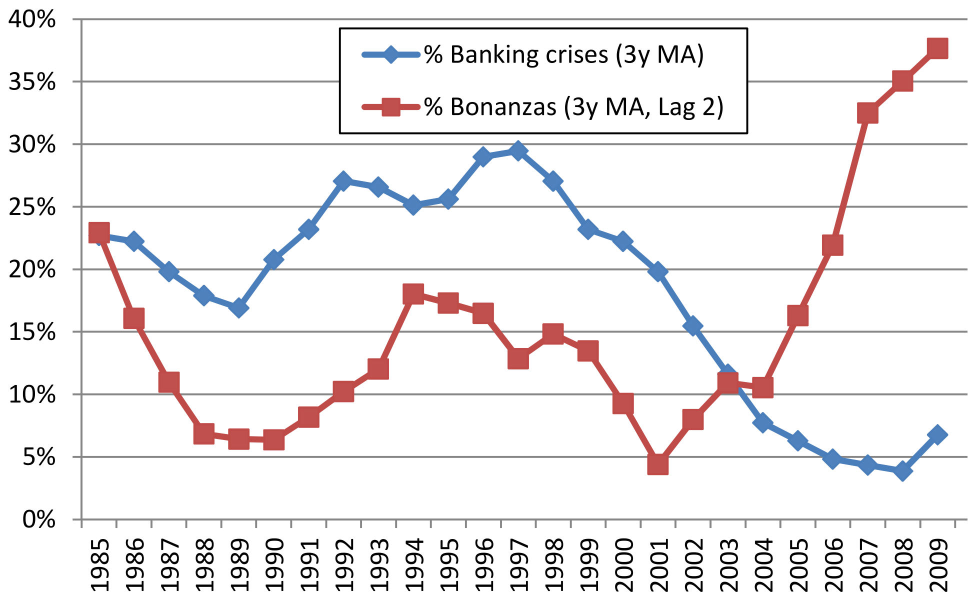

Figure 2: Capital flow bonanzas and crises

Notes: The figure shows the correlation between a lagged indicator of capital flow bonanzas and the percentage of countries suffering banking crises as defined by Reinhart and Reinhart (2008).

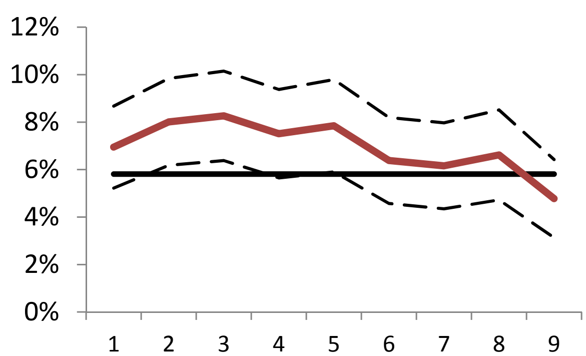

Figure 3: Conditional probability of crisis after capital flow bonanza

Notes: This figure depicts the probability of a crisis in a country that has experienced a capital inflow bonanza t years ago, together with a 95% confidence interval. For comparison, the straight horizontal line indicates the unconditional probability of a crisis.

1.2 Literature

Our paper is related to the positive literature on financial amplification, such as Bernanke and Gertler (1989) and Kiyotaki and Moore (1997), who have studied the positive aspects of financial amplification in a single sector. Mendoza (2001, 2010) and Aoki, Benigno and Kiyotaki (2008) apply this analysis to the case of a small open economy. By contrast, we develop a multi-country model in which different countries may suffer from financial amplification and crisis at different times, allowing us to study the spillover effects of such episodes of financial amplification among countries.

Devereux and Yetman (2010) and Nguyen (2010) also develop multi-country models of financial amplification, but they do so in a framework in which financial constraints are always binding so amplification effects always at work. In our setup, financial amplification occurs infrequently – it arises endogenously when an economy is hit by an adverse shock of sufficient magnitude. This allows us to study what macroprudential measures a country can take in normal times when financial constraints are loose as a precaution against future binding constraints.

Our paper is also related to Caballero, Farhi and Gourinchas (2008) who describe "moving bubbles" as instances in which one sector in the world economy becomes financially more constrained and capital moves on to other less constrained sectors. In our work, binding financial constraints in one part of the world economy also lead to higher capital flows to other parts. However, we focus on how such flows make the recipient countries more vulnerable to financial crises in subsequent periods. Martin and Ventura (2010) examine rational bubbles in an environment with financial amplification effects.

Our paper also investigates the normative aspects of multi-country financial amplification dynamics. This is related to a growing literature on financial amplification and externalities, as studied e.g. by Caballero and Krishnamurthy (2003), Korinek (2007, 2009, 2010, 2011b), Lorenzoni (2008), Jeanne and Korinek (2010, 2011ab) and Bianchi (2011). The insight in these papers is that decentralized agents do not internalize that their privately optimal financing decisions make the economy in aggregate more vulnerable to episodes of financial amplification. For example, borrowers take on an excessive amount of finance, creating a role for macroprudential regulation. While the existing literature has studied such regulation exclusively from a single-country perspective, the contribution of this paper is to develop a general equilibrium model of the world economy in order to study the optimal response of macroprudential measures to events external to a given country. We show that external factors such as crises in other parts of the world economy lead to increased capital flows ("hot money"). This magnifies the incentives for borrowers to take on larger debts and larger exposure to financial fragility, leading to higher externalities and, in turn, a greater need for macroprudential regulation. In addition, our paper sheds light on the general equilibrium effects that arise when multiple countries in the world economy impose macroprudential regulations.

Tobin (1978) argues that real factors such as labor and capital adjust more slowly than prices in international financial markets, and that untamed movements in international financial markets may therefore have painful real consequences. He famously concludes that it may be desirable "to throw some sand in the wheels of our excessively efficient international money markets." Tobin's argument is based on broad but unspecific concerns about the undesirability of sharp movements in financial markets, but he does not provide a welfare analysis of why such movements may be socially inefficient and merit policy intervention. By contrast, our paper analyzes a specific externality that arises when economies experience binding financial constraints and are subject to financial amplification effects. This provides a clear welfare rationale for capital controls. Tobin proposes a general tax on all foreign exchange transactions in order to avoid sharp exchange rate movements. We instead propose a tax on debt inflows, since we view the buildup of leverage as the main factor that creates the risk of sharp financial adjustments.

Although this paper focuses exclusively on ex-ante measures to deal with financial crises, Benigno et al. (2010) and Jeanne and Korinek (2011b) also study the role of ex-post stimulus interventions to address financial crises. The general result in these papers is that policymakers would always want to engage in a mix of ex-ante prudential and ex-post stimulus measures when faced with the risk of financial crises that involve financial amplification.

The sectoral structure of our model is related to Korinek, Roitman and Végh (2010) who capture the phenomenon of "decoupling" and "recoupling" during the 2008/09 financial crisis. They describe decoupling as a situation when one part of the world economy is financially constrained and can no longer demand capital or other factors, which lowers world factor prices and benefits the remaining unconstrained sectors. The same role is played by "hot money" in this paper: financial crisis and financial constraints in one country lead to capital flows to other countries, which benefits them by lowering the interest rates at which they borrow. However, this paper adds an important dimension to the debate by showing that the capital flows that accompany an episode of decoupling are a mixed blessing: they not only provide a benefit to the recipient countries by lowering their cost of borrowing, but they also lead to greater future financial instability. Decoupling therefore strengthens the case for macroprudential policy action.

2 Model Setup

We describe a model of the world economy in infinite discrete time $t = 0, 1, ...$ The world economy consists of two types of agents: (i) international investors who represent "hot money" and who hold savings that they move where return opportunities are greatest; (ii) different countries who borrow and who are subject to an endogenous collateral constraint. We describe each in detail.

2.1 International Investors

We assume that international investors come in overlapping generations:[3] each period, a continuum of mass one of investors are born who live for two periods. We denote the variables of investors with the superscript h (as in "hot money" or "households"). Investors value consumption according to a neoclassical period utility function $v(c)$ that satisfies $v'(c) > 0 > v''(c)$, with time discount factor β, resulting in a total level of utility

$$v\left(c_t^h\right) + \beta v\left(c_{t+1}^h\right)$$

In our applications below, we will focus on the special case $v(c) = \log(c)$ so as to obtain analytical solutions. Investors obtain the constant endowments e_1 and e_2 in the first and second period of their lives. In the first period, they choose how much to consume c_t^h and how much to save in zero coupon bonds at the gross world interest rate R_{t+1}, where $\frac{b_{t+1}^h}{R_{t+1}}$ denotes the amount saved. In the second period of their lives, they obtain the repayment b_{t+1}^h on their bond holdings, consume all their remaining wealth and perish. The optimization problem of generation t investors (in short notation) is

$$\max_{c_t^h, c_{t+1}^h, b_{t+1}^h} v\left(c_t^h\right) + \beta v\left(c_{t+1}^h\right) \quad \text{s.t.} \quad \begin{aligned} c_t^h + \frac{b_{t+1}^h}{R_{t+1}} &= e_1 \\ c_{t+1}^h &= e_2 + b_{t+1}^h \end{aligned}$$

which yields the standard Euler equation

$$v'\left(c_t^h\right) = \beta R_{t+1} v'\left(c_{t+1}^h\right) \tag{1}$$

For arbitrary utility functions, the response of b_{t+1}^h to changes in the interest rate is

$$\frac{\partial b_{t+1}^h}{\partial R_{t+1}} = \frac{\frac{b_{t+1}^h}{R_{t+1}} v''\left(c_t^h\right) - \beta R_{t+1} v'\left(c_{t+1}^h\right)}{v''\left(c_t^h\right) + \beta R_{t+1}^2 v''\left(c_{t+1}^h\right)} > 0$$

If $b_{t+1}^h > 0$, the repayment to investors rises with the market interest rate.

Note that the decision problems of different generations of investors are not directly linked. This greatly simplifies our analysis – equation (1) defines a time-invariant supply of funds function $b^h(R)$ that satisfies $\partial b^h / \partial R > 0$.

In the case of log-utility, the Euler equation can be solved explicitly for a supply of funds function. We obtain the following expressions for the amount of net savings and bond holdings

$$\frac{b^h(R)}{R} = \frac{\beta e_1 - e_2/R}{1+\beta}, \qquad b^h(R) = \frac{\beta R e_1 - e_2}{1+\beta} \tag{2}$$

[3] As we will see below, this formulation leads to a time-invariant supply of funds function that greatly simplifies our numerical analysis and therefore allows us to efficiently simulate a setup with multiple borrowing countries.

Both expressions are increasing in R, i.e. investors save more and receive greater repayments when the interest rate is high. Furthermore, the supply of "hot money" is higher the larger the initial endowment e_1 compared to the second-period endowment e_2. The inverse demand function is

$$R\left(b^h\right) = \frac{(1+\beta)\, b^h + e_2}{\beta e_1}$$

2.2 Borrowing Countries

We assume that borrowers in the world economy consist of two symmetric regions of identical atomistic countries of mass 1 each. For simplicity, we call the two regions "North" and "South," denoted by the superscripts N and S respectively. Each country in turn consists of a unit mass of identical atomistic agents who are infinitely lived. In each country, there is one unit of a Lucas tree with a stochastic payoff process that is i.i.d. We denote the payoff processes of the trees in the "North" and "South" region as $\left\{y_t^N\right\}$ and $\left\{y_t^S\right\}$ respectively. We assume that within a given region, the endowment processes are identical across countries, and within a given country they are identical across agents.

Agents value consumption according to the period utility function $u(c)$, which they discount at factor β. We denote the variables of a representative borrower in a representative country within region $i \in \{N, S\}$ by the superscript i. They maximize the expectation of their lifetime utility

$$E_t \left\{ \sum_{s=t}^{\infty} \beta^{s-t} u\left(c_s^i\right) \right\} \tag{3}$$

A representative borrower in region i holds a_t^i units of the Lucas tree of his country. We assume that the tree can only be owned by local agents in the country, otherwise it becomes worthless. This captures in a simplified manner that real assets cannot be transferred costlessly, because of technological reasons or incentive reasons.

Each period, the representative agent i chooses how much to consume c_t^i and how much to borrow in world capital markets, denoted by his bond holdings b_{t+1}^i, which will typically be negative to capture borrowing. The agent also chooses the holdings a_{t+1}^i of the tree in his country that he wishes to carry into the next period, where the prevailing market price of the tree is denoted by p_t^i. The budget constraint of type i agents is

$$c_t^i + \frac{b_{t+1}^i}{R_{t+1}} + a_{t+1}^i p_t^i = a_t^i \left(y_t^i + p_t^i\right) + b_t^i \tag{4}$$

Since the tree can only be held by type i agents, we will find that market clearing and symmetry imply that $a_t^i \equiv 1$ in equilibrium for all agents for all countries in region i.

One of the crucial assumptions about borrowers is that their access to finance is limited by an incentive problem. We assume that they have an opportunity to move their assets into a fraudulent scam after borrowing in period t, and that international investors can detect this and take legal action, but only if they do so in the period that the fraud is committed. Because of imperfect legal enforcement, international investors can seize at most an amount ϕ of the asset holdings of borrowers, which they can re-sell to other agents on the domestic market in country i at the prevailing asset price p_t^i. This implies that abstaining from fraud is incentive-compatible for domestic agents in country i as long as[4]

$$\frac{b_{t+1}^i}{R_{t+1}} \geq -\phi p_t^i \tag{5}$$

This requirement imposes a collateral constraint that limits debt to a fraction ϕ of the current value of equity holdings of agents in country i. The optimization problem of a representative type i borrower can be expressed as maximizing (3) subject to (4) and (5). Assigning the shadow price λ_t^i to the collateral constraint, the first-order conditions to the problem are

$$u'\left(c_t^i\right) = \beta R_{t+1} E_t\left[u'\left(c_{t+1}^i\right)\right] + \lambda_t^i \tag{6}$$

$$p_t^i u'\left(c_t^i\right) = \beta E_t\left[u'\left(c_{t+1}^i\right)\left(y_{t+1}^i + p_{t+1}^i\right)\right] \tag{7}$$

The second condition iterated forward yields the standard asset pricing equation

$$p_t^i = E_t\left[\sum_{s=t+1}^{\infty} \beta^{s-t} u'\left(c_s^i\right) y_s^i\right] \Bigg/ u'\left(c_t^i\right)$$

3 Decentralized Equilibrium

The decentralized equilibrium in the economy is a set of allocations and prices that simultaneously solve the optimization problems of international investors and representative borrowers in all countries in the two regions of the world economy, subject to market clearing in international bond markets,

$$b_t^h + b_t^N + b_t^S = 0 \qquad \forall t$$

Using this condition allows us to denote the vector of state variables in the economy as $s = \left(b^N, b^S, y^N, y^S\right)$, of which the first two are endogenous and the last two are exogenous and i.i.d. By combining the optimality conditions of international investors and representative borrowers in each region, we describe the decentralized equilibrium as recursive functions of the vector of the state

[4] An alternative specification would be to assume that international investors can seize up to a fraction ϕ of the asset holdings of borrowers, which would entail the term $-\phi a_{t+1}^i p_t^i$ on the right hand side of the incentive-compatibility constraint. As discussed in Jeanne and Korinek (2010), the implications of the two setups are largely identical.

variables s for $i, j \in \{N, S\}$ and $i \neq j$,

$$\begin{aligned} c^i(s) &= \min\left\{b^i + y^i + \phi p^i(s); (u')^{-1}\left(\beta R'(s) E\left[u'\left(c^i(s')\right)\right]\right)\right\} \\ p^i(s) &= \frac{\beta E\left[u'\left(c^i(s')\right)\cdot\left(y^{i\prime} + p^i(s')\right)\right]}{u'\left(c^i(s)\right)} \\ R'(s) &= \frac{e_2 - (1+\beta)\left(b^{i\prime}(s) + b^{j\prime}(s)\right)}{\beta e_1} \\ \text{and } b^{i\prime}(s) &= R'(s)\cdot\left[b^i + y^i - c^i(s)\right] \end{aligned} \tag{8}$$

where the last equation captures the evolution of the endogenous state variables. Appendix B describes how to numerically solve for these recursive functions.

3.1 Deterministic Equilibrium

To develop some intuition about the workings of the economy, we first solve for the equilibrium in a deterministic world economy that satisfies $y_t^N = y_t^S = \bar{y}$ for all agents in all countries and that starts out with common initial bond holdings in the two regions $b_0^N = b_0^S = b_0$. For notational convenience we drop the superscripts N and S for all region-specific variables in this subsection.

Steady State A deterministic steady state in the world economy is characterized by a constant level of bond holdings $b = b_{SS}$ of the representative agents in the two regions and of bonds holdings $b^h = -2b_{SS}$ of international investors. Given a steady-state interest rate of R_{SS}, the resulting steady state levels of consumption and of asset prices in all countries are

$$c_{SS} = \bar{y} + \frac{R_{SS} - 1}{R_{SS}} b_{SS} \qquad \text{and} \qquad p_{SS} = \frac{\beta \bar{y}}{1-\beta}$$

Unconstrained Steady State If the steady state bond holdings satisfy $b_{SS} > -\phi p_{SS}/\beta$, then the equilibrium in the world economy is strictly unconstrained and the steady-state interest rate satisfies $R_{SS} = 1/\beta$. This interest rate is consistent with the optimization problem of international investors if the amount borrowed lies on their supply schedule (2), implying

$$b^h = -2b_{SS} = \frac{e_1 - e_2}{1+\beta} \tag{9}$$

This is the amount of saving that allows international investors to have a smooth consumption profile. In such an equilibrium, the intertemporal marginal rates of substitution of international investors and of borrowing countries all equal the market-clearing world interest rate.

An unconstrained long-run steady state is indeed feasible if the fundamental parameters of the world economy satisfy

$$b_{SS} = b_{SS}^{unc} = \frac{e_2 - e_1}{2(1+\beta)} \geq -\frac{\phi \bar{y}}{1-\beta} \tag{10}$$

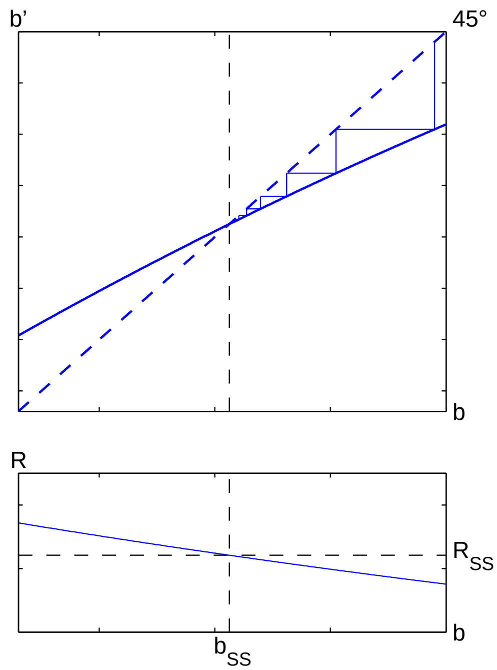

Figure 4: Unconstrained Dynamics

Notes: The solid line in top panel of the figure illustrates the next-period wealth function $b'(b)$ in the absence of binding constraints as well as the dashed 45 degree line. The steady state is where the two lines intersect and is indicated by the vertical dashed line b_{SS}. The bottom panel reports the world interest rate under the given allocations.

Unconstrained Dynamics If this condition is satisfied, then the world economy will converge to the unconstrained steady-state in the absence of shocks. Starting from an unconstrained initial debt level of b_0, we employ the Euler equation of domestic agents in conjunction with the equilibrium interest rate relationship of investors (2) to describe the evolution of the economy as

$$u'(c_t) = \beta R(b_{t+1}) u'(c_{t+1})$$

The phase diagram of a world economy with an unconstrained steady state is depicted in figure 4. If borrowers start out with less debt than in steady state, i.e. $b_t > b_{SS}$, then the world economy is located to the right of the dashed vertical line in the figure. Investors reduce the interest rate $R_{t+1} < R_{SS}$ to entice borrowers to increase their debt. Given the price signal provided by the low interest rate, borrowers find that $\beta R_{t+1} < 1$ and it is optimal for them to choose a declining consumption path and accumulate more debt, as depicted by the zigzag line in the figure. Asymptotically, borrowers dissave until the world interest rate satisfies $\beta R_{t+1} = 1$. As this situation is reached, all agents (i.e.

borrowers as well as international lenders) have a smooth consumption profile. The opposite dynamics arise when the initial debt level is more than steady state $b_t < b_{SS}$.

It is of particular interest for our analysis of the stochastic model below to focus on the behavior of the world interest rate as the economy converges to its steady state: as depicted in the bottom part of figure 4, the interest rate starts out at a low level when unconstrained representative agents borrow little and gradually increases as debt rises and the world economy converges to its steady state.

Constrained Steady State If condition (10) is not satisfied, then the deterministic steady-state in the world economy is constrained. In that case, the debt holdings of borrowers are determined by the constraint, i.e. they borrow as much as possible without violating incentive compatibility,

$$\frac{b_{SS}}{R_{SS}} = -\phi p_{SS} = -\frac{\phi \beta \bar{y}}{1-\beta}$$

The equilibrium interest rate of investors at that debt level satisfies $\beta R_{SS} = \frac{e_2 - 2(1+\beta) b_{SS}}{e_1} < 1$, i.e. borrowers in the economy permanently have incentives to dissave, but the constraint prevents them from doing so. This illustrates that binding financial constraints depress the world interest rate because they reduce the availability of investment opportunities for international lenders.

We solve the two equations to obtain

$$b_{SS}^{con} = -\frac{\phi \bar{y} e_2}{(1-\beta) e_1 - 2(1+\beta) \phi \bar{y}} > b_{SS}^{unc}$$

Constrained Dynamics Assume that the world economy enters period t with a wealth level of borrowers $b_t < b_{SS}^{con}$. Then borrowing that period is determined by the level of the constraint

$$b_{t+1} = -\phi R_{t+1} p_t \tag{11}$$

However, note that the variable p_t in this equation is endogenous. In particular, if $b_t < b_{SS}^{con}$, then borrowing agents have lower wealth than in steady state. Given that they are financially constrained, they cannot engage in optimal consumption smoothing. Therefore $u'(c_t) > u'(c_{t+1})$ and the period t asset price p_t declines below its steady-state value. The declining asset price implies that the borrowing limit in equation (11) is reduced further and borrowers are forced to cut back even more on domestic consumption than if the asset price had remained at its fundamental level. The equilibrating process in period t can be viewed as a feedback loop of falling borrowing, falling asset prices and falling consumption, as is typical in models of financial amplification. The process is also commonly referred to as "deleveraging."

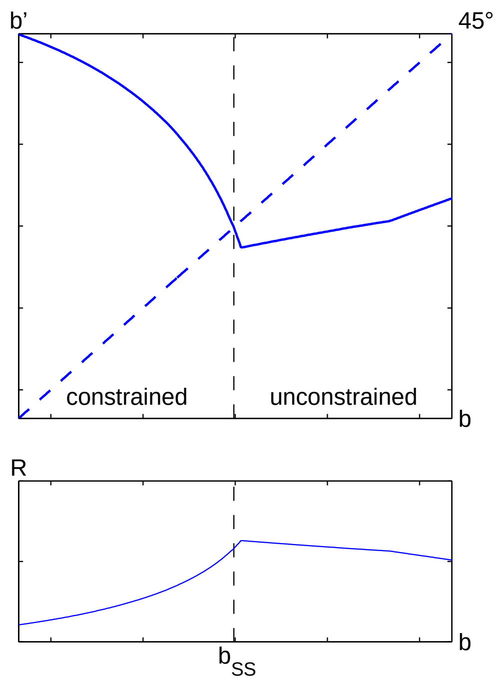

Figure 5: Constrained Dynamics

Notes: The top panel shows the next-period wealth function $b'(b)$ as well as the 45 degree line in an economy that is constrained in steady state. When the constraint $b'(b)$ is binding the function is strictly declining; for loose constraints it is strictly increasing. The bottom panel indicates how the resulting credit demand affects the world interest rate.

As illustrated in figure 5, the next-period wealth function b' is therefore non-monotonic. If the equilibrium is characerized by binding constraints, then lower b (i.e. higher debt) implies more severe financial amplification effects in the current period and a higher b' (i.e. less debt) in the next period. On the other hand, if the equilibrium is unconstrained, then lower b in the current period implies lower b' in the next period as the optimal unconstrained consumption path of borrowers implies that they decumulate assets.

The lower panel of the figure illustrates the effects on the world interest rate: if financial constraints are binding, then lower wealth b implies tighter constraints, a lower effective demand for credit from constrained borrowers, and a lower world interest rate. By contrast, if financial constraints are loose, then lower wealth b implies greater demand for borrowing and a higher interest rate. The equilibrium world interest rate is therefore a non-monotonic function of the wealth level of borrowers in the world economy.

3.2 Comparative Statics

In this subsection, we investigate analytically how individual borrowing countries are affected by changes in some of the model parameters. In order to obtain analytic results, we make several simplifying assumptions. Suppose that the world economy is in its unconstrained steady state so that $\beta R_{SS} = 1$ for all time periods $t \geq 1$. In period $t = 0$, assume that the prevailing world interest rate is given by R_1. The steady state level of consumption from period 1 onwards is $c^j_{SS} = \bar{y} + \frac{R_{SS}-1}{R_{SS}} b^j_1 = \bar{y} + (1-\beta)\, b^j_1$, i.e. borrowers consume their endowment minus the interest payments on their debt, which keeps their principal constant at b^j_1.

3.2.1 Interest Rates and Unconstrained Borrowing

Let us first assume an initial wealth level that is sufficiently high so that the economy is unconstrained, i.e. $b^j_1 \geq -\phi R_1 p^j_0$. Then the Euler equation of decentralized agents determines borrowing in period 0,

$$u'\left(\bar{y} + b^j_0 - \frac{b^j_1}{R_1}\right) - \beta R_1 u'\left(\bar{y} + (1-\beta)\, b^j_1\right) = 0$$

The variable that links the borrowing and lending decisions of all agents in all countries is the world interest rate. Let us therefore analyze the effects of changes in the world interest rate R_1 in our simplified framework:

Lemma 1 *If borrowing in period* 0 *is unconstrained, a lower interest rate* R_1 *increases the debt level* b^j_1 *carried into the future, as long as the debt level is not too large compared to the degree of relative risk aversion of borrowers.*

Applying the implicit function theorem to the Euler equation above yields

$$\frac{\partial b^j_1}{\partial R_1} = \frac{\beta u'\left(c^j_{SS}\right) - b_1/\left(R_1\right)^2 u''\left(c_0\right)}{-\beta\left(1-\beta\right) R_1 u''\left(c^j_{SS}\right) - u''\left(c_0\right)/R_1}$$

The denominator of this equation is always positive, and the numerator is positive as long as $\frac{b_1}{R_1}\frac{u''(c_0)}{u'\left(c^j_{SS}\right)} < \beta R_1$ or, for $\beta R_1 \approx 1$, approximately $-\frac{b_1}{R_1}D\left(c_0\right) < c_0$, i.e. borrowing times the degree of relative risk aversion $D\left(c_0\right)$ is less than consumption. This is always the case in our calibrations below.

3.2.2 Financial Amplification

Next we assume that the initial debt level b^j_0 in the economy is so large that the borrowing constraint in period 0 is binding and agents cannot carry their preferred level of debt into the future. A binding financial constraint implies that the economy experiences financial amplification and deleveraging in period 0.

Analytically, we substitute the binding constraint $b^j_1 = -\phi R_1 p^j_0$ and write the period 0 budget constraint as $c^j_0 = b^j_0 + \bar{y} + \phi p^j_0$. Substituting this as well as $c^j_1 = c^j_{SS} = \bar{y} - \frac{R_{SS}-1}{R_{SS}}\phi R_1 p^j_0$ into the period 0 asset pricing equation yields

$$p^j_0 = \frac{u'\left(\bar{y} - (R_{SS}-1)\frac{R_1}{R_{SS}}\phi p^j_0\right)}{u'\left(\bar{y} + b^j_0 + \phi p^j_0\right)} p_{SS} \tag{12}$$

Both the left-hand side and the right-hand side of this equation are increasing in p_0. However, it can easily be seen that the slope of the right-hand side $\frac{\partial rhs}{\partial p_0}$ is lower than 1 for sufficiently low values of $\phi \leq \hat{\phi}$, guaranteeing a unique equilibrium in the small open economy.[5] This allows us to find the following comparative static result:

Lemma 2 *The lower the economy's initial level of liquid net worth $b^j_0 + y^j_0$, the stronger financial amplification effects in country j, i.e. the lower is the local level of asset prices p^j_0, the tigher is the financial constraint and the less the economy can borrow. Financial amplification magnifies the impact of changes in liquid net worth on consumption $\partial c^j_0/\partial b^j_0 > 1$.*

Applying the implicit function theorem to equation (12) and employing the assumption $\frac{\partial rhs}{\partial p^j_0} < 1$, it can be readily seen that $\partial p^j_0/\partial b^j_0 > 0$ and by implication $\partial c^j_0/\partial b^j_0 > 1$, i.e. changes to the initial liquid net worth of borrowers lead to amplified changes in consumption. Since the borrowing limit in period 0 is given by ϕp^j_0, a lower asset price also implies a tighter borrowing limit.

3.2.3 Interest Rates and Financial Amplification

We next investigate how exogenous changes in the world interest rate affect the extent of financial amplification if an economy experiences binding constraints:

[5] A detailed derivation of the uniqueness of equilibrium is given in the appendix of Jeanne and Korinek (2010). They find the threshold that guarantees uniqueness to be $\hat{\phi} \approx 0.09$ for typical parameter values.

Lemma 3 *The lower the world interest rate R_1 in period 0, the stronger financial amplification effects in country j, i.e. the lower is the local level of asset prices p_0^j, the tigher is the financial constraint, the less the economy borrows, and the lower consumption in period 0.*

Again, the result can be obtained by applying the implicit function theorem to equation (12) and observing that $\partial p_0^j / \partial R_1 > 0$. A lower world interest rate lowers the asset price in the small open economy j in period 0. Since the borrowing limit in period 0 is given by ϕp_0^j, a lower asset price also implies a tighter borrowing limit and lower period 0 consumption. Furthermore, observe that the welfare effects of higher interest rates are negative since country j is a net borrower.

Discussion We found in section 3.1 that binding constraints in the world economy lead to lower interest rates. The heuristic result described in lemma 1 of this subsection suggests that these lower interest rates induce countries to take on a higher debt burden, which by lemma 2 makes them more vulnerable to financial amplification effects. Furthermore, the financial amplification effects will be stronger if world interest rates are low. These effects are the basic building blocks of our argument. In section 5, we will demonstrate these findings in a calibrated version of the full model.

4 Planning Problem

This section analyzes how a constrained planner who internalizes the feedback effects that arise during financial amplification can improve welfare in an economy. In general, the decentralized allocations in an economy subject to amplification effects are not constrained efficient, because each borrower i takes the future value of collateral assets in his country as given, even though asset prices are driven by the joint behavior of all agents in the economy. Since the level of asset prices determines the tightness of collateral constraints, a *pecuniary externality* among borrowers within a given country arises: an individual borrower does not internalize that his borrowing decisions will affect the level of asset prices and by extension the tightness of collateral constraints of other borrowers when amplification effects arise. We will show below that a planner who internalizes this externality can offset the distortion by imposing a Pigouvian tax on capital inflows. The contribution of this paper to the literature is to analyze how the level of externalities and the optimal policy response in one country is affected by events in other parts of the world economy, and to study the global general equilibrium effects of macroprudential regulation.[6]

Analytically, we describe the behavior of a time-consistent policymaker located in a representative small country in region i of the world economy. Since

[6] For an analysis of such pecuniary externalities in a small open economy setup see e.g. Korinek (2010).

the country under observation is small, the policymaker in the country takes equilibrium in international financial markets and the world interest rate as given. However, in contrast to decentralized agents, the policymaker internalizes the general equilibrium effects of her actions in the domestic economy, including the effects on the level of the asset price p^i. We assume that she recognizes that $a^i \equiv 1$ in any symmetric equilibrium.

The objective of the planner is then to determine the amount of consumption c^i and borrowing b^i_{t+1} of domestic agents so as to maximize welfare in her country, as given by equation (3), subject to the budget constraint (4) and the borrowing constraint (5). The borrowing constraint depends on the level of the asset price in the economy. We assume that the planner does not set the asset price directly, but instead internalizes that her allocations affect the net worth and the marginal utilities of private domestic agents, which in turn determine asset prices through the equilibrium condition (8). One interpretation for this is that private domestic agents are allowed to trade the asset after the planner has determined their consumption and borrowing allocations. A reason why the planner may not want to directly interfere in asset markets is that private agents enjoy an informational advantage in determining asset prices. From equation (7), we find that private agents price the asset such that

$$p^i_t = \frac{\beta E_t \left[u'\left(c^i_{t+1}\right)\left(y^i_{t+1} + p^i_{t+1}\right)\right]}{u'\left(c^i_t\right)}$$

In a time-consistent equilibrium in period t, the planner in a small country of the world economy observes b^i_t and y^i_t and chooses today's consumption c^i_t and borrowing b^i_{t+1} of domestic agents while taking the equilibrium in world capital markets, as summarized by the vector of state variables s_t, and the allocations chosen by the planner in future periods as given. In the equation above, a planner internalizes that her choice of b^i_{t+1} affects the values of c^i_{t+1} and p^i_{t+1} that will be chosen by the time-consistent planner next period. We therefore denote the asset price as a function of the beginning-of-period b^i_t, the variables c^i_t and b^i_{t+1} over which the planner has control, and the exogenous state variables that include y^i_t and all information determining R_{t+1} as

$$p^i_t = p\left(b^i_t, c^i_t, b^i_{t+1}; s_t\right)$$

If the planner chooses to borrow and consume the maximum amount possible given the constraint, then her borrowing would be

$$b^i_{t+1} = -\phi R_{t+1} p\left(b^i_t, c^i_t, b^i_{t+1}; s_t\right)$$

This equation defines a unique level of b^i_{t+1} for sufficiently low $\phi \leq \hat{\phi}$, as we had assumed earlier, which in turn results in a unique level of consumption $c^i_t = y^i_t + b^i_t - b^i_{t+1}/R_{t+1}$. We denote the level of the asset price that prevails under this allocation as the function $\bar{p}\left(b^i_t; s_t\right)$, which depends only on b^i_t and s_t since the two variables b^i_{t+1} and c^i_t are set to their maximum level. This function is strictly increasing and continuously differentiable in b^i_t and reflects the level of the asset price that is relevant for the planner whenever the constraint in the economy is binding.[7] The fact that the function depends only on b_t^i reflects that the planner has effectively no choice variables left when the constraint is binding – all she can do is to borrow and consume the maximum possible. On the other hand, when the borrowing constraint is loose in a given period, the equilibrium asset price is greater than $\bar{p}\left(b_t^i; s_t\right)$. Therefore the planner therefore recognizes that she can view the borrowing constraint relevant to her problem as

$$-\frac{b_{t+1}^i}{R_{t+1}} \leq \phi\bar{p}\left(b_t^i; s_t\right) \tag{13}$$

The optimization problem of a planner in a representative country i is to maximize (3) subject to the budget constraint (4) and the borrowing constraint (13). Using the budget constraint to substitute for c_t^i and assigning the shadow price λ_t^i to the borrowing constraint, the planner has a single choice variable b_{t+1}^i. Taking the first order condition yields an Euler equation of

$$u'(c_t^i) = \lambda_t^i + \beta R_{t+1} E_t\left[u'(c_{t+1}^i) + \lambda_{t+1}^i \phi\bar{p}'(b_{t+1}^i; s_{t+1})\right] \tag{14}$$

Compared to the decentralized Euler equation (6) there is an additional term $\lambda_{t+1}^i \phi\bar{p}'(\cdot)$, which reflects that saving more today increases the asset price by the derivative $\bar{p}'(\cdot)$ next period. Doing so relaxes the collateral constraint by $\phi\bar{p}'(\cdot)$ units, which increases utility at rate λ_{t+1}^i if the constraint is binding.

If the economy is in a position where there is no risk of a crisis next period, then $E_t\left[\lambda_{t+1}^i\right] = 0$ and the planner's Euler equation coincides with that of decentralized agents. The absence of crisis risk in the following period implies that the planner will not intervene. On the other hand, when the world interest rate is low, e.g. because other parts of the world economy have just suffered a crisis, then the incentive to borrow for unconstrained borrowers is particularly strong . Under such circumstances, the tightness of constraints λ_{t+1}^i in case of a future crisis will be higher and macro-prudential regulations that lean against the wind of capital inflows are particularly desirable.

4.1 Implementation

We assume that the policymaker can levy a state-contingent tax τ_t on collateralized borrowing from abroad by residents of the domestic economy and rebate the tax receipts in lump sum fashion. By comparing the Euler equations of decentralized agents (6) and the planner (14), it can be seen that the optimal tax on international borrowing that implements the constrained social optimum satisfies

$$\tau\left(b_t; s_t\right) = \frac{\phi\beta R_{t+1} E_t\left[\lambda_{t+1}\bar{p}'(b_{t+1}; s_{t+1})\right]}{u'\left(c_t\right)}$$

This expression corresponds to the externality term from equation (14) above, normalized by the marginal utility of current consumption. Since we

[7] See Jeanne and Korinek (2010) for a more detailed derivation.

assumed the domestic economy is small, taxing borrowing does not affect the world interest rate and the allocations of international investors. The tax is fully borne by domestic agents. However, since the tax alleviates an existing inefficiency, it improves welfare.

Naturally, there are a number of equivalent ways in which the policy objective can be achieved. Instead of imposing direct taxes on capital inflows, policymakers frequently impose unremunerated reserve requirements. Specifically, market participants who bring money into the domestic economy have to park a fraction of the amount in a reserve account with the central bank that does not accrue interest. The opportunity cost of holding money in an unremunerated account, i.e. the lost interest, can be seen as the equivalent of a tax. The level of such an unremunerated reserve requirement urr would therefore have to be set to

$$urr\left(b_t; s_t\right) = \frac{\tau\left(b_t; s_t\right)}{R_{t+1} - 1 + \pi_{t+1} + \tau\left(b_t; s_t\right)} \tag{15}$$

where π_{t+1} represents the expected inflation rate. One limitation to this instrument is the following: if world interest rates and inflation rates are low, the opportunity cost of tying up capital in a reserve account is low, implying that high levels of reserve requirements have to be chosen to impose a tax of a given magnitude. Analytically, this is captured by.the terms in the denominator – for low R_{t+1} and π_{t+1} the reserve requirement approaches 100%. Furthermore, when the level of world interest rates is low, small fluctuations in interest rates may require large movements in the optimal level of unremunerated reserve requirements.

Quantity measures are equivalent to price measures in our simple model, but in practice it is more difficult to calibrate their correct magnitude, and they provide larger incentives for evasion when the quota on inflows is binding. See Korinek (2010) for further discussion.

In practice, policymakers often express concerns not only about rising asset prices but also about appreciating exchange rates when they impose controls on capital inflows. While the model presented in this paper does not explicitly model the exchange rate, a broader interpretation of the mechanism we describe applies. In particular, the exchange rate can be viewed as one of several asset prices in the economy that experiences booms during episodes of inflows and busts when capital flows reverse. In many instances, the reason why policymakers are averse to strong appreciations of the exchange rate is that they are aware that these may be followed by depreciations. Korinek (2007, 2010) illustrates that exchange rate depreciations may lead to financial amplification effects that are similar to those arising from asset price declines in this paper, with similar externalities. In the context of emerging market economies, exchange rate depreciations are of particular concern when borrowers have taken on dollar debts (see also Korinek, 2011a).[8]

[8] A separate and important concern is that the costs of an overvalued exchange rate fall

5 Quantitative Results

5.1 Calibration of Parameters

We calibrate our model at annual frequency since asset price busts typically occur over several quarters. Given this time frame, we choose a value of $\beta = 0.96$ to correspond to the typical annual discount rate in the literature. The coefficient of relative risk aversion of borrowing agents is taken as $\gamma = 2$. For international investors, we maintain a log-utility function.

Under the parameter values chosen so far, the steady-state asset price to output ratio of borrowers is $p_{SS} = 24$. We set the parameter ϕ in the borrowing constraint to $\phi = .015$ to target a steady-state external debt to output ratio of $b_{SS} = -.36$, which corresponds to the average external indebtedness of the countries included in the World Bank's Global Development Finance database.

We assume that the output process in both regions of the world economy is i.i.d. and follows a binominal distribution $y_t^i \in \{y_H, y_L\}$, where y_H and y_L capture booms and busts, with busts occuring with a probability of $\pi = .03$, i.e. on average three times a century, reflecting the incidence of crises over the past century. We normalize $y_H = 1$ and calibrate $y_L = .94$ so as to match the average decline in detrended output in G-7 countries during the most recent crises.[9]

We calibrate the parameters of international investors such that there is a small shortage of investment opportunities in steady-state. In a marginally unconstrained deterministic steady state, total savings of international investors would be $b_{SS}^h = -2b_{SS} = -2\phi p_{SS}$. They would enjoy a smooth consumption profile with $c_t^h = \bar{c}$ and the world interest rate would satisfy $\beta R_{t+1} = 1$ if their endowments were $e_1 = \bar{c} + \beta\theta b_{SS}$ and $e_2 = \bar{c} - \theta b_{SS}$ with $\theta = 2$. However, given the precautionary motive of borrowers, their credit demand in the stochastic equilibrium is less than p_{SS}. We therefore set $\theta = 1.9$ so that borrowers are marginally unconstrained in steady state. The parameter $\bar{c}$ determines the elasticity of the interest rate with respect to credit demand. We set $\bar{c} = 3$ to target a decline in the interest rate to zero if one of the two regions experiences a bust.

The parameter values are summarized in table 2.

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disproportionately on exporters, who may have disproportionate lobbying power.

[9] An alternative approach would be to approximate the output process $\{y_t\}$ by a discrete random variable with a larger number of states so as to resemble a continuous random variable. This would allow us to endogenize the threshold $\hat{y}_t$ of the endowment shock below which the economy experiences binding constraints and crises, and to make statements about this threshold. However, this would come at the expense of clarity in our analysis. Furthermore, given that financial crises are rare events, it is difficult to calibrate the precise probability distribution of the left tail of the process $\{y_t\}$. More generally, all of our results below that relate to the intensive margin of financial crises given $y_t = y^L$ (i.e. how severe they will be) apply equally to the extensive margin, as captured by the probability of a crisis and the threshold $\hat{y}_t$.

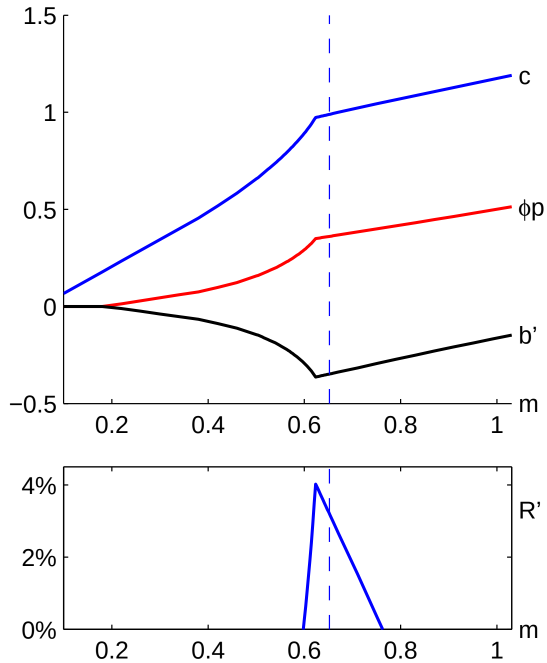

Figure 6: Policy functions c, p and b' and interest rate function

Notes: The upper panel of the figure depicts the policy functions c, p and b' as a function of the liquid net wealth $m = y^i + b^i$ of a representative borrower. The liquid net wealth in the other region is kept at its steady state level. The lower panel shows the resulting world interest rate R'.

β	γ	ϕ	y_H	y_L	π	θ	$\bar{c}$
0.96	2	0.015	1	0.94	3%	1.9	3

Table 2. Parameterization

Notes: The table reports the parameter values chosen for the calibration of our model.

5.2 Simulation Results

Figure 6 depicts the policy functions for b', ϕp and c of a representative borrower in region i as a function of his liquid net wealth $m = y^i + b^i$, while keeping the level of liquid net wealth of the other region j at its steady state value. All three policy functions exhibit a kink when the region switches from the constrained to the unconstrained region, which occurs at $m = 0.62$. To the left of this threshold, consumption and the asset price respond considerably more to changes in m than to the right of the threshold, since borrowing constraints are binding and the economy experiences financial amplification. The policy function b' is declining for constrained values of m since greater liquid net wealth implies a higher asset price and a higher borrowing limit. For unconstrained values of m, the policy function b' is increasing as the agent optimally smoothes consumption and carries more wealth into the future the more liquid wealth he possesses.

The dashed vertical line indicates the level of net wealth that is reached if the economy has been in the boom state for a long number of periods. For simplicity, we call this wealth level the high steady state.

The bottom panel of the figure shows the world interest rate R' as a function of liquid net wealth m, while keeping the liquid net worth in the other region at its steady state level. The interest rate is a mirror image of the policy function b' – the more the agent borrows, the higher the interest rate that international investors demand.

When a region is in its high steady state and experiences a bust shock $y_t = y^L$, it deleverages, i.e. its debt goes down (bond holdings increase). In our benchmark calibration, the economy's debt level declines by 7% of GDP, which equals the magnitude of the economy's current account reversal. Domestic absorption falls by 12%, and the domestic asset price collapses by 23%. Following a number of positive shocks y^H, the economy slowly returns to the steady state debt level b_{SS}.

In figure 7 we depict a sample simulation of the world economy with two regions. The first panel shows output and consumption in the North, and the second panel depicts the two variables in the South. In the given simulation, there are three instances of busts. The North experiences a single bust in period 18, whereas the South experiences busts in periods 4 and 20. In each such episode, consumption declines more strongly than output because falling asset prices and falling borrowing capacity reinforce the effects of the initial output shock.

The figure also illustrates the spillover effects of financial crises in one region to the other region: if the South experiences a bust in period 4 (panel 2), it becomes financially constrained and is forced to reduce its debt level. Given the lower effective world demand for capital, the world interest rate declines (panel 3).[10] This induces higher capital flows to the North, which temporarily borrows and consumes more (panel 1). If the North continues to experience positive output shocks, both countries in the world economy converge back to the high steady state.

However, if a region is hit by a negative output shock after its debt level has just gone up, then it is more vulnerable to financial crises and experiences more severe amplification effects. This is the situation of the South in period 20. In our simulation, the North suffers a financial crisis in period 18, and in response to the financial constraints in the North, world interest rates decline and hot money flows to the South, which takes advantage of the cheap credit by increasing its level of indebtedness. In period 20, the South suffers an adverse

[10] In crisis episodes, the real world interest rate turns slightly negative, which is consistent with the experience from the most recent financial crisis in 2008, or the East Asian crisis in 1997.

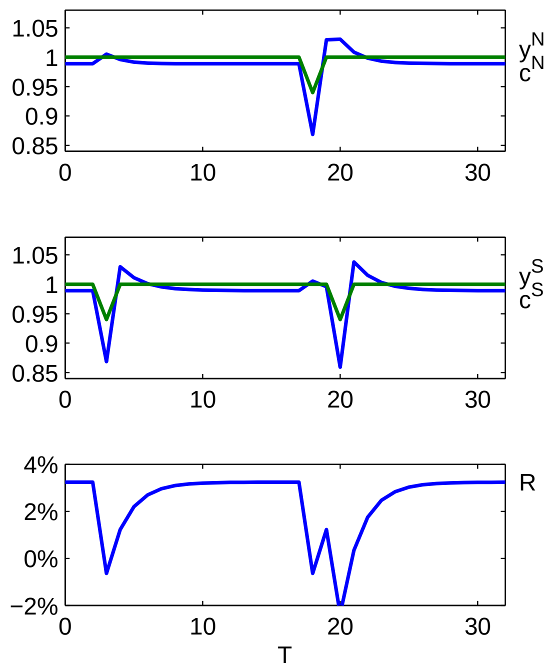

Figure 7: Simulated sample path of world economy

Notes: This figure illustrates a simulation of the world economy over 32 periods. Panel 1 shows the time path of output and consumption in the North. Panel 2 depicts the same two variables in the South. Panel 3 reports the path of the world interest rate.

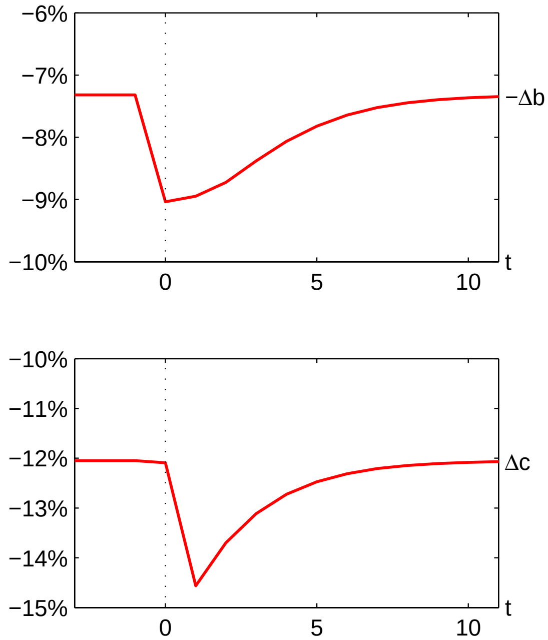

Figure 8: Impact of output shock on b and c

Notes: Panel 1 of the figure shows the impact of adverse output shocks on debt in one region t periods after the other region has experienced a financial crisis. Panel 2 illustrates the impact of such shocks on consumption.

shock and experiences a crisis that is significantly larger than the one in period 4 – absorption declines by 13.7% instead of 12%.

Figure 8 shows the impact of an adverse output shock y^L on the level of debt (panel 1) as well as on consumption (panel 2) t periods after a financial crisis in the other region. The decline in borrowing $-\Delta b$ can be interpreted as the extent of deleveraging in the economy and will materialize in the form of a current account reversal. The baseline – an adverse shock without a preceding crisis in the other region – is depicted for $t < 0$ and consists of a 7.3% decline in borrowing capacity and a 12% decline in consumption. If the shock hits in the aftermath of crises in other parts of the world economy, the decline in borrowing capacity is up to 9%, and the decline in consumption up to 14.6%.

5.3 Policy Measures

Given the risk of financial amplification effects and the associated externalities, policymakers in the described economies find it optimal to impose Pigouvian taxes on foreign borrowing in good times so as to mitigate the crises that occur in response to adverse shocks.

In our benchmark calibration, a planner finds it optimal to impose a tax on foreign borrowing in the amount of 1.89% in the high steady state. For example, if a borrower took on \$100 in foreign credit, the planner would impose a Pigouvian tax of \$1.89 per year. According to equation (15), in an economy with 2% inflation, the same effect could be achieved by imposing an unremunerated reserve requirement in the amount of 35%, i.e. if a borrower took on \$100 in foreign credit, he would be required to hold \$35 of that amount in an unremunerated reserve account. These magnitudes of inflow taxation or unremunerated reserve requirements are within the range of policy measures that have recently been enacted by a number of emerging economies.[11]

If a financial crises occurs somewhere else in the world economy, it is desirable to raise the tax to lean against the resulting flows of hot money. The top panel of figure 9 depicts the optimal macroprudential tax t periods after a crisis has occurred in the other region of the world economy. In the period the crisis occurs, the optimal level of the tax is 1.97%, and the corresponding reserve requirement would be 53%. Over the ensuing periods, it falls progressively back to the steady state level.

Panels 2 and 3 of the figure replicate the results of figure 8 given the optimal level of macroprudential taxation. The figures show the impact of an adverse shock in one region t periods after an adverse shock has occurred in the other region. The dashed line represents the impact in the decentralized equilibrium and the solid line under a planner's optimal intervention. The tax on foreign borrowing mitigates the effects of an adverse shock on consumption from 12% to 8.8% in the high steady state of the world economy. When the country has experienced inflows of hot money in the aftermath of a crisis in another region, the tax reduces the impact of an adverse shock on consumption from 13.7% to 10%. Similarly, optimal taxation reduces the current account reversal from 7.3% to 3.4% in the high steady state of the world economy, and from 9% to 4.4% when a country has experienced inflows of hot money in the aftermath of a financial crisis somewhere else.

We simulated the evolution of the world economy and the optimal macroprudential tax over a period of 200 time periods and depict the relationship between the optimal tax on the level of debt in a given region in figure 10. It can be seen that there is a very close relationship between the two variables that is almost linear. Regressing the optimal tax rate on a constant and the economy's level of debt yields that

$$\hat{\tau}_t = -.27 - .87 b_t$$

with an R^2 of .97.

Interpreting this relationship as a simple policy rule, an increase in capital inflows/GDP by 1 percentage point warrants an increase in the optimal level of capital inflow taxation by .87 percentage points in our sample economy. If net worth rises above $b = -.31$ in our example, the optimal level of the tax becomes zero as there is no risk of financial crisis in the following period.

[11] For example, Brazil imposed a 2% tax on capital inflows in Oct. 2009, which was later raised to 6%. Thailand implemented a 30% URR from 2006 to 2008, and Colombia a 40% URR in 2007, which was later increased to 50%. See Ostry et al. (2011).

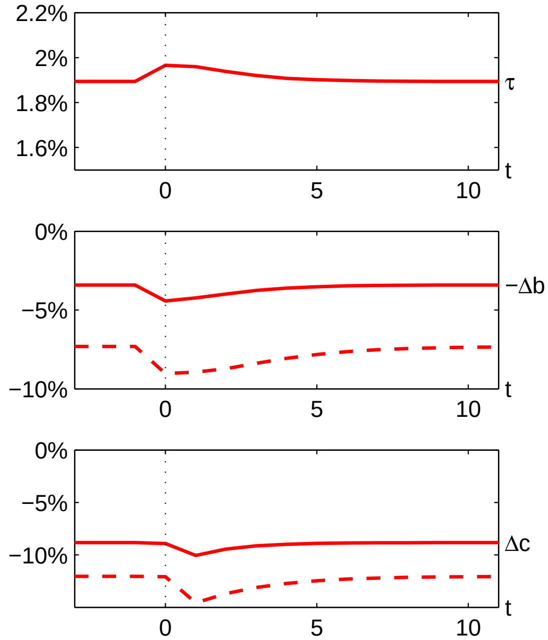

Figure 9: Optimal macroprudential taxation and impact of output shocks

Notes: Panel 1 of this figure reports the optimal level of macroprudential taxation in one region t periods after the other region has experienced a financial crisis. Panels 2 and 3 report the impact of adverse output shocks on borrowing and consumption: the solid lines represents the impact given the optimal policy intervention. For comparison, the dashed lines show the impact in the decentralized equilibrium.

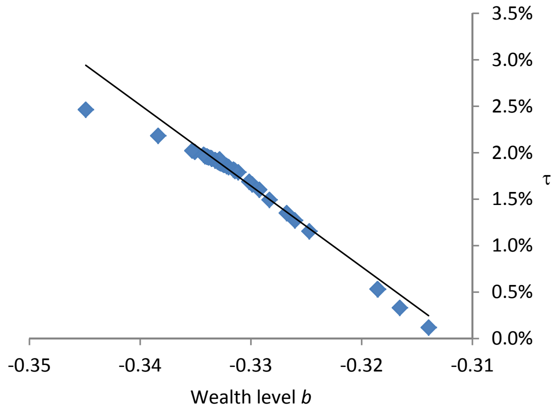

Figure 10: Response of macroprudential tax to changes in debt
Notes: The figure shows the relationship between the optimal macroprudential tax and the level of debt in a simulation of the world economy over 200 time periods.

It is also interesting to observe the effects of optimal capital flow taxation on the level of world interest rates. In the decentralized equilibrium without intervention, the world interest rate is 3.3% in the high steady state. If one region experiences a financial crisis, the resulting current account reversal pushes down the world real interest rate to $-.5\%$. On the other hand, when all countries impose the optimal level of macroprudential regulation, the world real interest rate is 1.6% in steady state, and it declines to only $-.2\%$ in the event of a crisis.

In welfare terms, we find that optimal capital inflow taxation increases a country's welfare in our model by the equivalent of a permanent increase in consumption by .4%, which is higher than most estimates of the welfare cost of business cycles.

6 Conclusions

This paper has developed a simple model of hot money and serial financial crises. Money is "hot" in the sense that countries that borrow and later suffer adverse shocks become subject to financial amplification effects that lead to a coordinated decline in consumption, borrowing, and asset prices. Individual market participants do not internalize that they expose their country to such amplification effects when they make their privately optimal borrowing decisions. As a result, they create an externality on other borrowers. A policymaker can induce market participants to internalize these effects by imposing macroprudential policies such as prudential controls on capital inflows. Such measures reduce macroeconomic volatility and improve welfare in the domestic economy.

The main focus of the paper was to show that crises in one region of the world economy lead to higher flows of hot money to other regions, which become in turn more vulnerable to future financial crises. For example, we showed that an adverse shock of a given size that normally leads to a 12% decline in domestic absorption will cause a 14.6% decline in domestic absorption if a country has just experienced inflows of hot money. By imposing a macroprudential tax on capital inflows of close to 2%, these magnitudes can be reduced to 8.8% and 10% respectively.

The admissibility of capital controls as a tool of macroeconomic management has recently been endorsed by researchers at the IMF (see e.g. Ostry et al., 2010, 2011), who propose that controls on capital inflows may indeed be desirable for countries who experience overvalued exchange rates and who have sufficent reserves and adequate fiscal and monetary policy. Our paper highlights one particular mechanism that provides a welfare rationale for such controls. We find that capital controls may also be desirable in case a country experiences asset price booms that are fuelled by capital inflows, not only in case of appreciations in the exchange rate, since the reversal of the credit flows that led to booms in asset prices may trigger financial amplification effects in which declining asset prices entail pecuniary externalities.[12]

The empirical literature, as summarized e.g. by Magud et al. (2011), finds that capital controls are generally effective in altering the composition of inflows, to some extent effective in reducing exchange rate pressures, but not necessarily effective in curbing the total volume of inflows. If the composition of inflows is successfully altered in favor of contingent financial instruments such as FDI or local currency debt, the externalities discussed in this paper will be reduced and the vulnerability to crisis will be diminished, as shown e.g. in Korinek (2009, 2010). In general, empirically identifying the effects of capital controls on the volume of inflows is difficult because of endogeneity problems – controls are most likely to be imposed when capital inflows are large, but this does not imply that capital controls cause larger inflows.

Forbes (2005) argues that capital controls may be undesirable since they increase the cost of finance. However, increasing the cost of borrowing from abroad so as to raise the private cost to the social cost is precisely the goal of such controls – the higher prices provide a market signal to borrowers to reduce the activity that imposes negative externalities on the rest of their economy.

There are a number of directions in which our research could be extended. One set of issues that deserves further analysis are the links between financial stability and growth. We analyzed the problem of hot money and serial financial crises in a model of an endowment economy, but our findings are likely to be very relevant for production economies. In such economies, private market participants expand the stock of capital during booms and the price of capital rises, enabling them to take on more credit. During busts, the stock of capital becomes less valuable and the collateral value declines. This may lead to a feedback spiral of declining borrowing capacity, falling asset prices, and fire

[12] However, declining exchange rates play a similar role and also entail pecuniary externalities during financial crises. See Korinek (2010).

sales. A policymaker who leans against the wind when credit flows into the economy may reduce excessive capital creation in booms, which mitigates the need for fire sales and the decline in asset prices plus the associated credit crunch in case of a bust, thereby increasing social welfare.

The problem is even further aggravated if investment has long-term effects on economic growth. Recent evidence (see e.g. IMF, 2009) suggests that credit crunches may have long-lasting detrimental effects on output because the investment lost during the crunch cannot be fully made up for during the ensuing recovery. Under such circumstances the welfare costs of financial crises are significantly greater than what we found in our numerical results because they stretch over many periods. See Jeanne and Korinek (2011a) for an investigation along these lines.

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A Data Sources

The stylized facts reported in the introductory part of the paper are based on four sets of variables that we obtained at annual frequency for 176 countries over the period of 1980-2009: As an indicator for the world interest rate, we use 10-year US Treasury bond yields deflated by the US consumer price index, which is smoothed by taking a three year moving average so as to remove sudden unexpected changes in inflation. Both variables are taken from the IMF's International Financial Statistics (IFS) database.

The dummy variable for capital flow bonanzas is calculated using IFS data according to the procedure of Reinhart and Reinhart (2008), i.e. a bonanza occurs when a country's current account balance as a percentage of GDP is in its top quintile. Dummy variable for banking crises are obtained from Reinhart and Rogoff (2009), Table A.3.1170. Dummy variables for currency crises are calculated using IFS data according to the procedure of Frankel and Rose (1996), i.e. a currency crisis occurs if a country's exchange rate depreciates by more than 25%, and if this depreciation in turns is at least 10% more than in the preceding period. Finally dummies for all crises are constucted by combining banking and currency crisis dummies.

The Granger causality tests in table 1 were performed using fixed effects panel regressions. We first included lags of the dependent variable and found that the only the first lag was significant. Then we augmented the regression with lagged values of the independent variable. In table 1 we report the resulting parameters and the associated t-values in parentheses. In both tests that are reported we can reject the hypothesis that the independet variables does not Granger-cause the dependent variable at the .1% level.

We also investigated a potential causal link between US banking crises and US 10-year bond yields by constructing an indicator of US bank failures from the FDIC list of failed banks as a proxy for banking sector problems in the US. However, we could not establish Granger-causality since FDIC assistance seemed to occur with a significant lag to the actual occurance of banking sector problems.

B Numerical Solution Method

Our numerical solution method is an extension of the endogenous gridpoint bifurcation method of Jeanne and Korinek (2010). Denote the beginning of period bond holdings for a representative agent in region i as b and for an agent in region j as d. The interest rate is a function of aggregate worldwide borrowing $R = R(b+d)$ as given by (2). Denote the total beginning of period liquid wealth holdings of agents in the two regions as $m = b + y$ and $n = d + z$. Our problem is to obtain policy functions $c(m,n)$, $p(m,n)$, $\lambda(m,n)$ and $b'(m,n)$. By symmetry this latter function is identical to $d'(n,m)$.

Taking advantage of the efficiency gains provided by the endogenous gridpoint bifurcation method requires setting up the problem in two nested loops.

B.1 Outer Loop

At the beginning of iteration k in the outer loop, we start with the policy functions $c_k(m,n)$, $p_k(m,n)$, $\lambda_k(m,n)$ and $b'_k(m,n)$, which is symmetric to $d'_k(m,n)$. (The initial policy functions can be set arbitrarily.)

B.2 Inner Loop

Each inner loop iteration starts with a given set of policy functions $\tilde{c}_l(m,d')$, $\tilde{p}_l(m,d')$ and $\tilde{\lambda}_l(m,d')$. (The initial functions can be set arbitrarily.) Taking $d'_k(m,n)$ from the outer loop as given, we calculate $\hat{c}(m,n) = \tilde{c}_l(m, d'_k(m,n))$ and similarly for $\hat{p}$ and $\hat{\lambda}$. In order to take advantage of the endogenous grid-points method, it is useful to perform our iterations over the grid (b',d') of end-of-period wealth levels. For any pair (b',d'), we calculate the world interest rate $R(b',d') = R(b'+d')$, which is obtained from lenders' optimality condition (2). Then we define

$$
\begin{aligned}
\mathfrak{C}(b',d') &= E\left[\hat{c}(m';n')^{-\gamma}\right] \\
\mathfrak{P}(b',d') &= E\left\{\hat{c}(m';n')^{-\gamma}\cdot\left[y'+p(m';n')\right]\right\}
\end{aligned}
$$

Then we solve the system of optimality conditions first under the assumption that the borrowing constraint is loose.

$$
\begin{aligned}
c^{\text{unc}}(b';d') &= \left\{\beta R(b'+d')\,\mathfrak{C}(b',d')\right\}^{-\frac{1}{\gamma}}, \\
p^{\text{unc}}(b';d') &= \frac{\beta\mathfrak{P}(b',d')}{c^{\text{unc}}(b';d')^{-\gamma}}, \\
\lambda^{\text{unc}} &= 0, \\
m^{\text{unc}}(b',d') &= c^{\text{unc}}(b',d') + \frac{b'}{R(b'+d')}.
\end{aligned}
$$

In the same way, we can solve for the constrained branch of the system for $b' \leq 0$ under the assumption that the borrowing constraint is binding in the current period as

$$
\begin{aligned}
p^{\text{con}}(b',d') &= \frac{-b'/R(b'+d')}{\phi}, \\
c^{\text{con}}(b',d') &= \left[\frac{\beta\mathfrak{P}(b',d')}{p^{\text{con}}(b',d')}\right]^{-\frac{1}{\gamma}}, \\
\lambda^{\text{con}}(b',d') &= c^{\text{con}}(b',d')^{-\gamma} - \beta R(b'+d')\,\mathfrak{C}(b',d'), \\
m^{\text{con}}(b',d') &= c^{\text{con}}(b',d') + \frac{b'}{R(b'+d')}.
\end{aligned}
$$

Concatenating constrained and unconstrained results as in Jeanne and Korinek (2010) allows us to obtain policy functions $\tilde{c}_{l+1}(m,d')$, $\tilde{p}_{l+1}(m,d')$ and

$\tilde{\lambda}_{l+1}(m, d')$ as well as $\tilde{w}'_{l+1}(m, d')$. The steps are iterated until convergence is reached. By employing the endogenous gridpoint bifurcation method, this loop converges very quickly.

Once the inner loop is completed, we observe that the two functions $\tilde{b}'_{l+1}(m, d')$ and the symmetric $\tilde{d}'_{l+1}(n, b')$ can be combined to

$$b' = \tilde{b}'_{l+1}\left(m, \tilde{d}'_{l+1}(n, b')\right)$$

Finding the root of this equation yields a function $b'_{k+1}(m, n)$ and the symmetric function $d'_{k+1}(n, m)$. This step is computationally more costly. However, by alternating iterating on the (efficient) inner loop with iterating on the (computationally costly) outer loop, the problem can be solved in an efficient manner. We substitute $d'_{k+1}(m, n)$ into $\tilde{c}_l(m, d')$, $\tilde{p}_l(m, d')$ and $\tilde{\lambda}_l(m, d')$ to obtain $c_{k+1}(m, n)$, $p_{k+1}(m, n)$, $\lambda_{k+1}(m, n)$ and iterate until convergence.