International Capital Controls

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Abstract

This paper provides a theoretical support for a macroprudential regulation of capital flows into emerging markets. We study a model of a production economy where 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 leads to a feedback spiral of declining borrowing capacity, falling asset prices, and fire sales. We attribute collateral constraints to be a driving force behind current account reversals and domestic absorption. The paper analyzes the role for macro-prudential policies to lean against the wind when credit flows into the economy. These policies reduce excessive capital creation in booms, and increase social welfare by mitigating the need for fire sales, asset price decline and associated credit crunch in case of a bust. We assess quantitatively that the optimal tax rate on capital inflows should be 1.5%. We find that credit crunches have long-lasting detrimental effects on output due to slow recovery of investment. One implication is that the welfare costs of financial crises are particularly large since they stretch over many periods. This suggests that adding investment channel is important for modelling financial amplification effects.

JEL Codes: E44, F32, F34, F43, G01, G15, G38, O16.

Keywords: hot money, financial fragility, serial financial crises, macro-prudential regulation, capital controls

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1 Introduction

Recent financial crises over the last decades in the world economy seem to have a recurrent pattern: when one country is hit by a credit crunch, capital flows out in a panic to the next attractive destination. The recipient country experiences a boom, asset price inflation and rising leverage, making it vulnerable to future adverse shocks.

Korinek (2011*b*) analyzed this pattern of hot money and serial financial crises in a stylized model of an exchange economy. This paper extends his research to production economy to study the effects of investment channel on output during serial financial crises. The model consists of two countries borrowing from a global investor. Credit is collateralized by countries' stocks of capital valued at market prices.

In booms, asset prices and borrowing capacity are high. Countries accumulate debt and expand the stock of capital. The price of capital rises, enabling economies to take on more credit. In busts, negative TFP shock causes the Fisherian debt deflation. Deleveraging leads to fire sales of assets, falling consumption, investment, production and aggregate demand. As a result, the stock of capital becomes less valuable, and the collateral value declines. Borrowing capacity decreases, credit constraint becomes binding and leads to further credit tightening.

The world interest rate is increasing in the amount countries want to borrow. As countries experience financial crises, the demand for loanable funds decreases. Global investors find fewer lending opportunities and the world interest rates decline. Healthy unconstrained economies find new incentives to take on more debt and become vulnerable to future busts. These spillover effects lead to global financial fragility and increase the risk of serial financial crises.

We find that credit crunches have long-lasting detrimental effects on output due to slow recovery of investment. This implies that the welfare costs of financial crises are particularly large since they stretch over many periods. This suggests that adding investment channel is important for modelling financial amplification.

The financial feedback loop entails credit externality if borrowing constraint is binding next period. In a decentralized competitive equilibrium, agents do not internalize the negative effects of asset fire-sales on the value of other agents' assets. As a result, agents borrow "too much" ex ante, compared with a social planner who internalizes the effects of feedback spirals that deleveraging depresses asset prices and borrowing capacity. The social planner lets asset prices be determined by the free market and takes the global interest rates as given. Regulating capital inflows social planner takes on less debt leading to less severe future constraints, less volatility and financial fragility.

The paper analyzes the role for macro-prudential policies to lean against the wind when credit flows into the economy. These policies reduce excessive capital creation in booms, and increase social welfare by mitigating the need for fire sales, asset price decline and associated credit crunch in case of a bust. This paper finds that a planner finds optimal to impose a tax on foreign borrowing in the amount of 1.5%. This level of tax on foreign borrowing mitigates the effects of an adverse shock on consumption from 15.5% to 13.3% in the aftermath of a crisis in another region. Similarly, optimal taxation reduces the current account reversal from 5% to 3% of GDP. This provides a rationale for macro-prudential regulation of capital flows such as recent 2% capital inflow taxation in Brazil. Another contribution of this paper to the literature is that it develops a numerical solution algorithm which is an extension of endogenous grid method in two dimensions.

2 Related Literature

The starting point for the analysis of capital controls effectiveness is a body of well-established literature, which demonstrates that financial crises in emerging economies can be understood as episodes of financial amplification. Fisher (1933), Bernanke and Gertler (1989), Greenwald and Stiglitz (1993), Kiyotaki and Moore (1997), Bernanke, Gertler and Gilchrist (1999), Aiyagari and Gertler (1999), Krugman (1999), and Aghion, Bacchetta and

Banerjee (2000) were among the first to show analytically that adverse conditions in the real economy and in financial markets mutually reinforce each other, leading to a feedback loop that propagates the financial and macroeconomic downturn. Calibration attempts produced varying results pertaining to the extent of amplification depending on the timing of collateral value, which was used as a basis. Studies that used a model of credit constraints that depend on the future value of collateral, such as Kiyotaki and Moore (1997), Caballero and Krishnamurthy (2001), Paasche (2001), and Krishnamurthy (2003), showed that even small, temporary shocks to technology can generate large, persistent fluctuations in output and asset prices. These studies, however, were criticized for the use of non-standard assumptions, which might have created the large amplification effects. Using a model with more standard assumptions Cordoba and Ripoll (2004) found a small amplification effect because the impact of current shocks on the future value of collateral in their model was mitigated by increased consumption of borrowers, increased investment and rising interest rates. By contrast, later studies by Mendoza and Smith (2006), Mendoza (2010), and Jeanne and Korinek (2010) used a model of credit constraints that depend on the current value of collateral assets and found quantitatively significant amplification effects. Our paper is similar to the latter papers in that it uses the model with the current value of collateral assets to model financial crisis and the effect of capital controls.

A number of authors, including Brunnermeier (2009), Adrian and Shin (2010) used financial amplification mechanism to explain the ongoing world-wide credit crisis. On the normative side, Caballero and Krishnamurthy (2003), Lorenzoni (2008), Jeanne and Korinek (2010), Korinek (2011*a*), Korinek (2012), and Stein (2012) analyzed the externalities of financial amplification. These normative studies used static three-period models and concentrated on qualitative effects. Therefore, the quantitative significance of pecuniary externalities, which is important for determining to what extent regulation is desirable for correcting this market failure, remained an open question. Bianchi (2011) considered a quantitative model of an emerging market economy with an infinite-horizon setup. In the model, which characterized optimal policy responses, real exchange rate depreciations could give rise to financial amplification. Korinek (2011*b*) considered an infinite-horizon setup, in which the deleveraging externality involved an asset price rather than the real exchange rate, which is applicable to both industrialized and emerging economies. Our paper continues the sequence of normative studies using a quantitative approach and asset-prices. However, unlike Korinek (2011*b*), who uses an exchange economy model, we are using a production economy model.

Mendoza and Bianchi (2010) also considered a normative production economy model, where borrowing and labor demand were constrained by asset prices. Their study used fixed interest rate, while our model uses linear upward sloping supply of loanable funds and allows us to model hot money similarly to Korinek (2011*b*) in the exchange economy model. In addition to that, Mendoza and Bianchi (2010) focused on a small open economy, whereas our study adds general equilibrium analysis of two countries and global investor. In our model 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. In their models constraints are always binding, while our model exhibits infrequent binding constraints arising endogenously in case of a large adverse shock. This allows us to analyze capital controls imposed at the times when financial constraints are loose as a precaution against future binding constraints.

Our paper studies optimal macroprudential regulation to reduce the cost of financial crises ex-ante, i.e. before a financial crisis materializes. Benigno et al. (2011), Benigno et al. (2013), and Jeanne and Korinek (2013) concentrate on ex-post stimulus interventions to address financial crises. The general result of 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.

3 Two-Country Model with Global Investor

Assume the world economy consists of two symmetric borrowing countries and a global investor.

3.1 Countries

There is a representative infinitely lived agent in each country $i = 1, 2$ producing a single tradable consumption-investment good using capital (k_t^i) and labor (h_t^i) inputs according to a Cobb-Douglas technology. The population is constant and is normalized to unity. Agents are endowed with one unit of time every period, which they allocate between market work and leisure. The agent maximizes the discounted utility of Greenwood-Hercowitz-Huffman form:

$$\max E_0 \sum_{t=0}^{\infty} \frac{\beta^t}{1-\sigma} \left(c_t^i - \theta \frac{{h_t^i}^{1+\gamma}}{1+\gamma} \right)^{1-\sigma} \tag{1}$$

where c_t^i denotes consumption of country i in period t. This choice of the utility function removes the wealth effect on labor supply by making the marginal rate of substitution between consumption and labor depend on labor only. This permits procyclical labour hours.

Countries have access to foreign risk-less bond market where they can borrow at the world risk free interest rate R_{t+1}. Country i faces the following budget constraint and law of motion for capital that features "adjustment costs" in investment:

$$c_t^i + x_t^i + b_t^i - \frac{b_{t+1}^i}{R_{t+1}} = y_t^i = z_t^i {k_t^i}^{\alpha} {h_t^i}^{1-\alpha} \tag{2}$$

$$k_{t+1}^i = (1-\delta) k_t^i + \Phi\left(\frac{x_t^i}{k_t^i}\right) k_t^i \tag{3}$$

where y_t^i, x_t^i and b_t^i are output, investment and external debt of country i at the start of period t; and $\alpha \in (0,1)$ is the factor share parameter. The stochastic technology level z_t^i is i.i.d. across time and countries. The adjustment cost function $\Phi(\cdot)$ is concave in investment to capture the difficulty of quickly changing the level of installed capital.

Let μ_t^i and $\mu_t^i q_t^i$ be the lagrange multipliers on the budget constraint (2) and capital accumulation equation (3) respectively. Following Hayashi (1982), since technology and adjustment costs have constant returns to scale, the marginal price of capital q_t^i is equal to the average price of installed capital (Tobin's q). Therefore, the market value of capital assets (stock market price p_t^i) is equal the product of the shadow value of capital q_t^i and the quantity of capital k_{t+1}^i

$$p_t^i = q_t^i k_{t+1}^i \tag{4}$$

Agents in each country are the sole capital owners in the economy. They can not sell or rent capital to foreigners, but they can use capital as collateral to borrow from the rest of the world. The amount of external debt that the country can roll over can not exceed the fraction $\phi < 1$ of the market value of its capital assets. We assume the international debt market is perfectly enforceable so that countries never default. This implies the following collateralized borrowing constraint similar to that in Kiyotaki and Moore (1997).

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

The optimization problem of the borrowing country i can be expressed as maximizing (1) subject to (2)-(5). Assigning the shadow price $\mu_t^i \lambda_t^i$ to the collateral constraint (5), the first-order conditions to the problem are

$$(1-\lambda_t^i) u_c(c_t^i, h_t^i) = \beta R_{t+1} E_t[u_c(c_{t+1}^i, h_{t+1}^i)] \tag{6}$$

$$(1-\phi\lambda_t^i) p_t^i u_c(c_t^i, h_t^i) = \beta E_t[u_c(c_{t+1}^i, h_{t+1}^i)(p_{t+1}^i + \alpha y_{t+1}^i - x_{t+1}^i)] \tag{7}$$

$$q_t^i \Phi'\left(\frac{x_t^i}{k_t^i}\right) = 1 \tag{8}$$

$$\theta {h_t^i}^{1+\gamma} = (1-\alpha) y_t^i \tag{9}$$

3.2 Global Investor

The global investor has a two period overlapping generations structure. Born at time t he smoothes the fall in his endowment income $e_1 > e_2$ by saving in non-contingent bond b_{t+1} at the interest rate R_{t+1}.

$$\max_{c_t, c_{t+1}, b_{t+1}} \quad \log(c_t) + \beta \log(c_{t+1}) \qquad \text{s.t.} \quad c_t + \frac{b_{t+1}}{R_{t+1}} = e_1, \qquad c_{t+1} = e_2 + b_{t+1}$$

This leads to the following indirect supply of loanable funds function

$$R_{t+1}(b_{t+1}) = \frac{(1+\beta)b_{t+1} + e_2}{\beta e_1} \tag{10}$$

Countries are linked only through international bond market:

$$b_{t+1} = b^1_{t+1} + b^2_{t+1} \tag{11}$$

4 Decentralized Equilibrium

In a given period, the policy and asset price functions of each country can be expressed in terms of their *beginning-of-period* external debt levels, (b_1, b_2), capital stocks, (k_1, k_2), and technology levels, (z_1, z_2). Let $s = (s_1, s_2)$ denote the vector of states $s_i = (b_i, k_i, z_i)$. The dynamic programming problem of country i can be expressed as follows:

$$\begin{aligned}
& V_i(s) = \max_{c_i, h_i, x_i, b'_i, k'_i} u(c_i, h_i) + \beta E[V_i(s')] & \\
\text{s.t.} \quad & c_i + x_i + b_i - \frac{b'_i}{R'(b'_1 + b'_2)} = z_i {k_i}^{\alpha} {h_i}^{1-\alpha} & (\mu_i) \\
& k'_i = (1-\delta)k_i + \Phi\left(\frac{x_i}{k_i}\right)k_i & (\mu_i q_i) \\
& \frac{b'_i}{R'(b'_1 + b'_2)} \leq \phi q_i k'_i & (\mu_i \lambda_i)
\end{aligned}$$

Decentralized equilibrium for this economy is given by consumption, labor supply and investment decision rules for each country, $c_i(s)$, $h_i(s)$, $x_i(s)$; laws of motion for capital and debt for each country, $k_i'(s)$, $b_i'(s)$; average capital asset price functions for each country $q_i(s)$; savings and interest rate functions for global investor, $b(s)$, $R(s)$; such that:

1. Given the pricing functions and the laws of motion, the value function and decision rules of each country solve that country's dynamic problem (1-5).

2. Savings and interest rate functions solve the global investor's problem (10).

3. International bond market clears (11).

The decentralized equilibrium can be expressed as recursive functions of the vector of the state variables s that solve the equilibrium conditions of two borrowing countries (2)-(9) and global investor (10)-(11). Appendix 7 shows how to solve for these recursive functions numerically using endogenous grid method.

5 Social Planner

The decentralized equilibrium entails credit externality that arises during financial amplification when borrowing constraint becomes binding. The borrowers in each country take asset prices in their country as given. They do not internalize that their borrowing decisions during booms drive up asset prices and relax the collateral constraint for other borrowers in the economy. Similarly, deleveraging decisions during busts lead to fire sales of assets, depress asset prices and further tighten the credit for other agents in the economy. These borrowing decisions are not constrained efficient from the point of view of a social planner who can internalize these feedback effects and improve welfare in an economy.

This section shows that a planner can offset the distortion by imposing a Pigouvian tax on capital inflows. Compared with a social planner, agents in decentralized economy borrow "too much" ex ante. By regulating capital inflows, social planner takes on less debt leading to less severe future constraints, less volatility and financial fragility. This paper analyzes how the level of externalities and the optimal policy response in one country is affected by events in other parts of the world economy. It studies the global general equilibrium effects of macroprudential regulation.

Social planner lets asset prices be determined by free market and takes global interest rates $R(b)$ as given. Policymaker in country i views the borrowing constraint relevant to her problem as

$$\frac{b^i_{t+1}}{R_{t+1}} \leq \phi p^i_t(b^i_t) = \phi q^i_t(b^i_t) k^i_{t+1} \tag{12}$$

The optimization problem of the social planner in country i is to maximize (1) subject to the budget constraint (2), law of motion for capital (3) and the borrowing constrain (12). Assigning the shadow price $\mu^i_t \lambda^i_t$ to the borrowing constraint, the first order condition w.r.t. debt yields an Euler equation

$$(1-\lambda^i_t) u_c(c^i_t, h^i_t) = \beta R_{t+1} E_t[u_c(c^i_{t+1}, h^i_{t+1})(1 + \phi \lambda^i_{t+1} \frac{\partial p^i_{t+1}}{\partial b^i_{t+1}})] \tag{13}$$

Comparing to the decentralized Euler equation (6), the Euler equation in the planners equilibrium differs by the extra term $\phi \beta R_{t+1} E_t[u_c(c^i_{t+1}, h^i_{t+1}) \lambda^i_{t+1} \partial p^i_{t+1} / \partial b^i_{t+1}]$. This externality kernel can be interpreted as follows: $\partial p / \partial b$ captures an increase in asset price due to additional borrowing, ϕ reflects resulting relaxation in the borrowing constraint, and $u_c \lambda$ represents the utility cost of constraint.

5.1 Implementation

Optimal regulation can be implemented by a state-contingent tax τ^i_t that the social planner levies on foreign debt and rebates back as lump sum transfers:

$$c^i_t + x^i_t + b^i_t - (1-\tau^i_t) \frac{b^i_{t+1}}{R_{t+1}} = y^i_t + T^i_t$$

The debt tax introduces a wedge in the Euler equation:

$$(1-\lambda_t^i-\tau_t^i)u_c(c_t^i,h_t^i)=\beta R_{t+1}E_t[u_c(c_{t+1}^i,h_{t+1}^i)]$$

and replicates the constrained social optimum if it is set to

$$\tau_t^i=\frac{\phi\beta R_{t+1}E_t\left[u_c(c_{t+1}^i,h_{t+1}^i)\lambda_{t+1}^i\frac{\partial p_{t+1}^i}{\partial b_{t+1}^i}\right]}{u_c(c_t^i,h_t^i)}$$

6 Model Results

6.1 Parameterization

The model was calibrated using annual frequency with the discount rate $\beta=0.96$, coefficient of relative risk aversion $\sigma=2$, capital share $\alpha=0.3$, and depreciation rate $\delta=0.08$.

Under these parameters, capital to output ratio of borrowers is $\bar{p}=\bar{k}=2.47$ in deterministic steady state with $\beta R=1$. The leverage ratio ϕ was calibrated to 0.07 to target the external debt to output ratio of 20%. The GHH utility parameters $\gamma=1$ and $\theta=2.54$ were calibrated to target the Frisch elasticity to 1 and hours worked to 0.36 of available time.

The technology process in both countries is assumed to be i.i.d. across time and countries and follows a binomial distribution $z_t^i\in\{z_H,z_L\}$, where z_H and z_L capture booms and busts, with busts occurring on average three times a century ($\pi=3\%$). The technology shock z_H was scaled to normalize output to one in booms, and z_L was scaled to match 6% decline in productivity during busts.

The functional form for Φ is specified as $a_1(x_t/k_t)^{1-1/\xi}+a_2$, as in Jermann (1998), where a_1 and a_2 are constants chosen such that the steady state level of capital is invariant to ξ. The curvature parameter ξ determines the severity of adjustment costs. As ξ approaches infinity, Φ becomes linear, and investment is converted into capital one for one (frictionless economy limit). At the other extreme, as ξ approaches zero, Φ becomes a constant function, and the capital stock remains constant regardless of the investment level (exchange economy limit). I set $\xi = 0.4$, which is broadly consistent with the values reported in the empirical literature.

To calibrate the parameters of global investors, we use the deterministic steady state and $\beta R = 1$. In this case, investors enjoy constant consumption of $c_t = c_{t+1} = \bar{c} = \frac{e_1+\beta e_2}{1+\beta}$ and save constant amount $b_{t+1} = 2\bar{b} = \frac{e_1-e_2}{1+\beta}$ where $\bar{b} = \phi\bar{p}$ is the debt of each country. This implies that endowments are $e_1 = \bar{c} + 2\beta\bar{b}$ and $e_2 = \bar{c} - 2\bar{b}$. The parameter $\bar{c}$ determines how interest rate responds to changes in credit demand. Higher values of $\bar{c}$ lead to smaller fluctuations in interest rate. We set $\bar{c} = 3$ to target a decline in the interest rate to zero if one of the countries experiences a bust.

Table 1 summarizes the parameter choices.

Table 1: Parameterization

Parameter		Value
β	Time discount rate	0.96
σ	Relative risk aversion	2
α	Capital share	0.3
ϕ	Leverage ratio	0.015
$1/\gamma$	Frisch elasticity	1
θ	Labor supply coefficient	2.54
ξ	Adjustment cost coefficient	0.4
δ	Depreciation rate	0.08
y_H	Output in booms	1
z_L/z_H	Productivity decline during crisis	0.94
π	Probability of crisis	3%
$\bar{c}$	Interest rate response to credit demand	3

6.2 Results

Figure 1 depicts the policy functions for b', ϕp and c of a borrowing country i experiencing positive shock z_h^i as a function of its debt b^i while keeping the level of capital and all states of the other country j at their steady state values. All three policy functions exhibit a kink when the region switches from the unconstrained to the unconstrained region, which occurs at $b =$

0.197. To the right of this threshold, consumption and the asset price respond considerably more to changes in debt level than to the left of the threshold since borrowing constraints are binding and the economy experiences financial amplification. For unconstrained values of b, the policy function b' is increasing as the agent optimally smoothes consumption and carries less wealth in the future by borrowing more today. For constrained values of b, the policy function b' is declining since greater indebtedness implies a lower asset price and a lower borrowing limit.

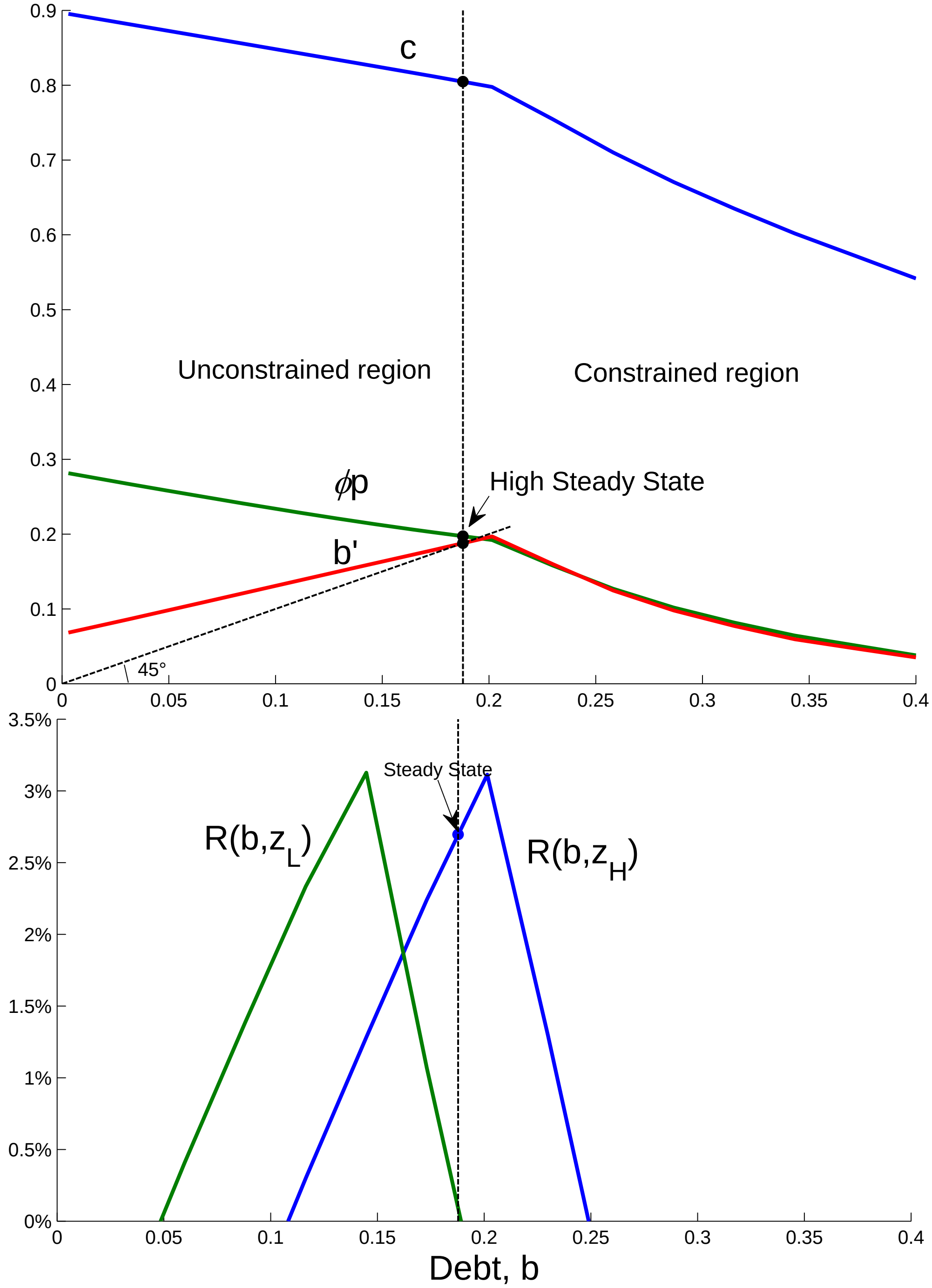
The dashed vertical line indicates the level of debt that is reached if the economy has been in the boom state for a long number of periods. For simplicity, we call this debt level the high steady state.

The bottom panel of the figure shows the two world interest rates R during booms z_H and busts z_L as a function of debt b while keeping the capital in the domestic country and all states in the foreign country at their steady state levels. The interest rate is a scaled image of the policy function b' – the more agent borrows, the higher the interest rate that international investors demand. The interest rate drops to zero in the event of a bust, due to calibration of $\bar{c}$.

In figures 2 and 3 we depict a sample simulation of the world economy with two countries. They show percentage deviations of output, consumption, asset prices, hours worked, investment, capital and global interest rate from the high steady state values for both countries. The top two panels of figure 3 also show the current account reversals as changes in debt as a percentage of GDP. There are two simulations given by the solid and dashed line. Under both scenarios country 1 experiences a single bust in period 4. Under the solid line scenario, country 2 does not experience any busts. Whereas under the dashed line scenario, country 2 experiences a bust in period 2.

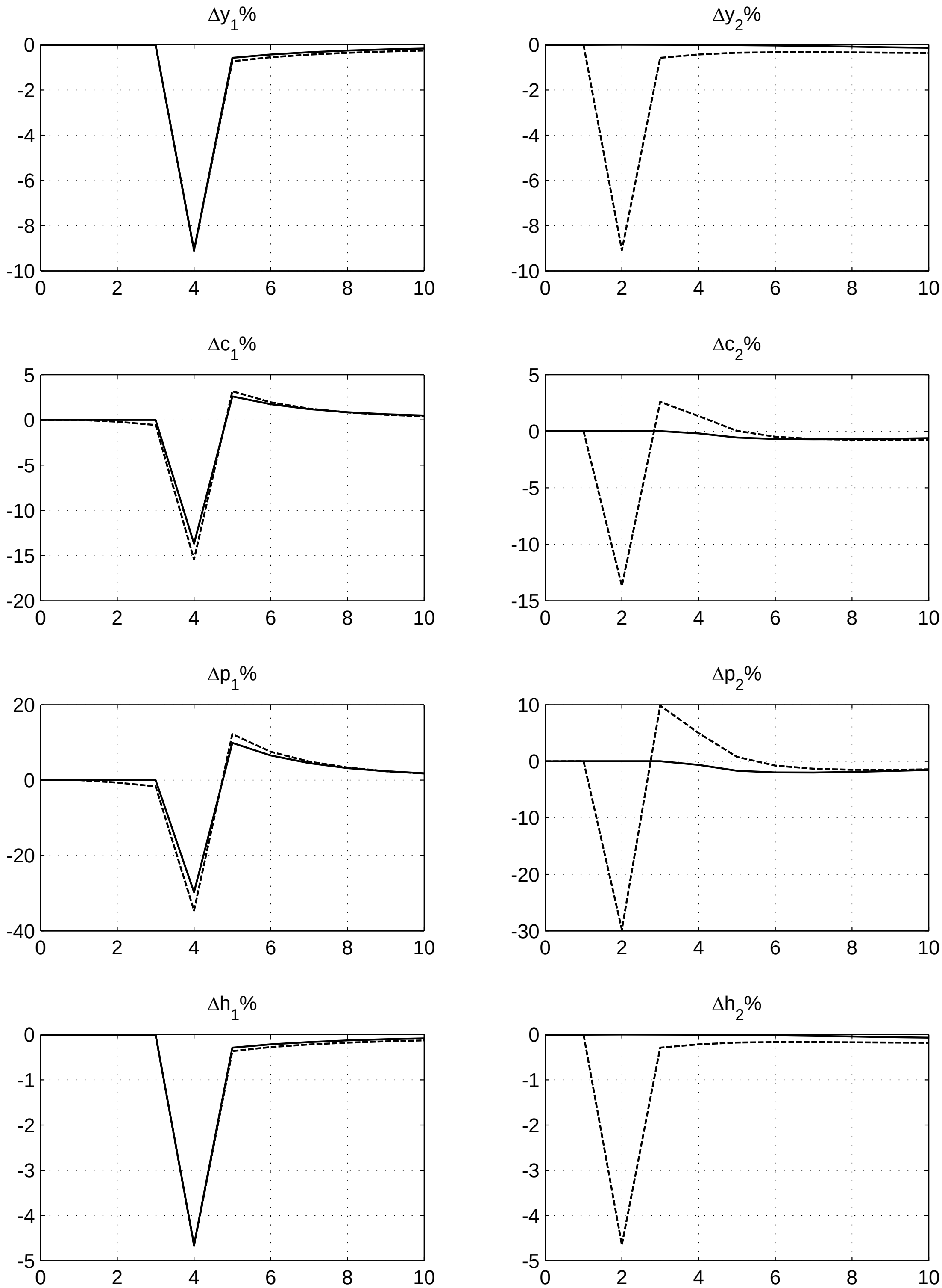
When a region is in its high steady state and experiences a bust shock $z_t = z_L$, it deleverages, i.e. its debt goes down. Under the benchmark calibration, the economy's debt level declines by 5% of GDP, which equals the magnitude of the economy's current account

Figure 1: Policy functions c, p and b' and interest rate function.



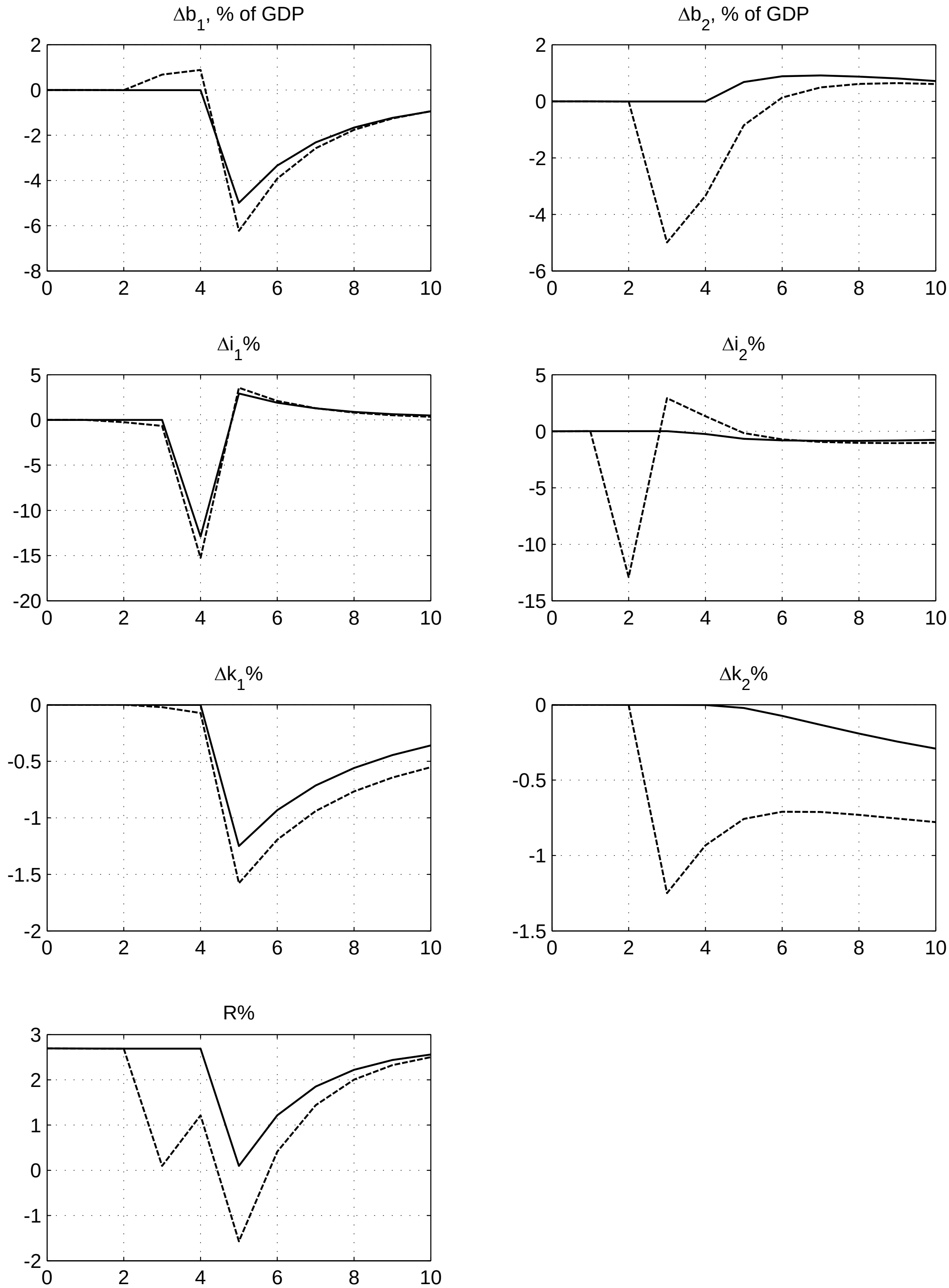
The upper panel of the figure depicts the policy functions c, p and b' as a function of the debt b of a representative agent in the borrowing country. The domestic capital and all states in the other country are kept at their steady state levels. The lower panel shows the resulting world interest rate R.

Figure 2: Simulated sample path of output, consumption, asset prices and labour hours



This figure illustrates a simulation of the world economy over 10 periods. The solid line represents the case when country 1 experiences shock in period 4 without country 2 experiencing any shocks. The dashed line represents the case when beside the shock in country 1 in period 4, there is a shock in country 2 in period 2.

Figure 3: Simulated sample path of debt, investment, capital and global interest rate



This figure illustrates a simulation of the world economy over 10 periods. The solid line represents the case when country 1 experiences shock in period 4 without country 2 experiencing any shocks. The dashed line represents the case when beside the shock in country 1 in period 4, there is a shock in country 2 in period 2.

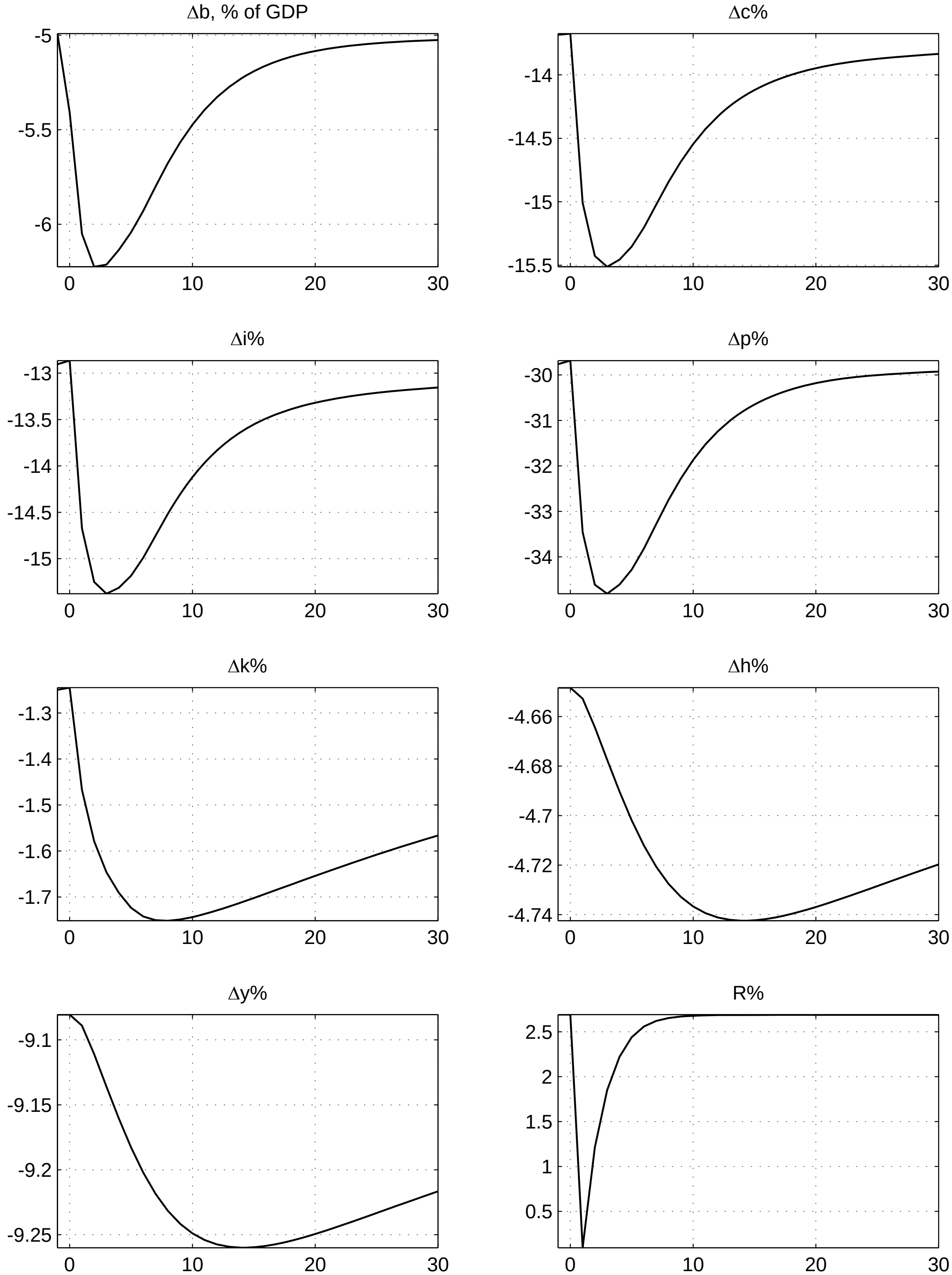
reversal. Domestic consumption falls by 13.7%, and the asset price collapses by 30%. In each such episode, consumption declines more strongly than output because falling asset prices and falling borrowing capacity reinforce the effects of the initial output shock. Following a number of positive shocks z_H, the economy slowly returns to the steady state debt level $\bar{b}$.

Adding investment channel proved to be important for financial amplification. Investment falls by 12.9% during a credit crunch and cannot be fully made up for during the ensuing recovery. In the aftermath of the crisis, investment recovered only up to 2.9% above pre-crisis levels. This has long-lasting detrimental effect on output which falls by 9.1% during a crisis and is still 1.7% below steady state in period 10. This implies that the welfare costs of financial crises are particularly large since they stretch over many periods.

Figures 2 and 3 also illustrate the spillover effect of financial crises in one region to the other region. If a country 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 situation is depicted by the dashed line. Under this scenario country 2 suffers a financial crisis at period 2, becomes financially constrained and is forced to deleverage. Given the lower world demand for capital, the word interest rate declines. This induces hot money flows to country 1, which takes advantage of the cheap credit by borrowing temporarily. If country 1 continues to experience positive shocks, both countries converge back to the high steady state. But if country 1 suffers an adverse shock at period 4 (dashed line), then it will experience a crisis that is significantly larger than the one under solid line episode. Table 2 reports the effects on all variables in country 1 at period 4 under two scenarios: in absence and presence of global financial fragility in the form of a prior crisis in country 2 at period 2:

Figure 4 shows the impact of an adverse shock z_L on the level of debt, consumption, investment, asset prices, capital stock, hours worked, output and global interest rate t periods after a financial crisis in the other country. The decline in borrowing Δb can be interpreted as the extent of deleveraging in the economy and will materialize in the form of a current

Figure 4: Impact of domestic shock delayed after foreign shock



This figure shows the impact of adverse output shocks on debt, consumption, investment, asset prices, capital stock, hours worked, output and interest rate if the domestic shock is delayed t periods after the other country experienced a financial crisis.

Table 2: Global financial fragility

Percentage change from steady state in country 1	No prior crisis in country 2	After crisis in country 2
Current account reversal, % of GDP	-5.0%	-6.2%
Output	-9.1%	-9.1%
Consumption	-13.7%	-15.4%
Asset price	-29.7%	-34.6%
Labor hours	-4.6%	-4.7%
Investment	-12.9%	-15.2%
Capital	-1.2%	-1.6%
Interest rate	0.1%	-1.6%

account reversal. The baseline – an adverse shock without a preceding crisis in the other region – is depicted for $t < 0$ and consists of decline in borrowing capacity of 5.0% of GDP and a 13.7% decline in consumption from the high steady state. If the shock hits in the aftermath of crises in other parts of the word economy, the decline in borrowing capacity is up to 6.2% of GDP, and the decline in consumption up to 15.4%.

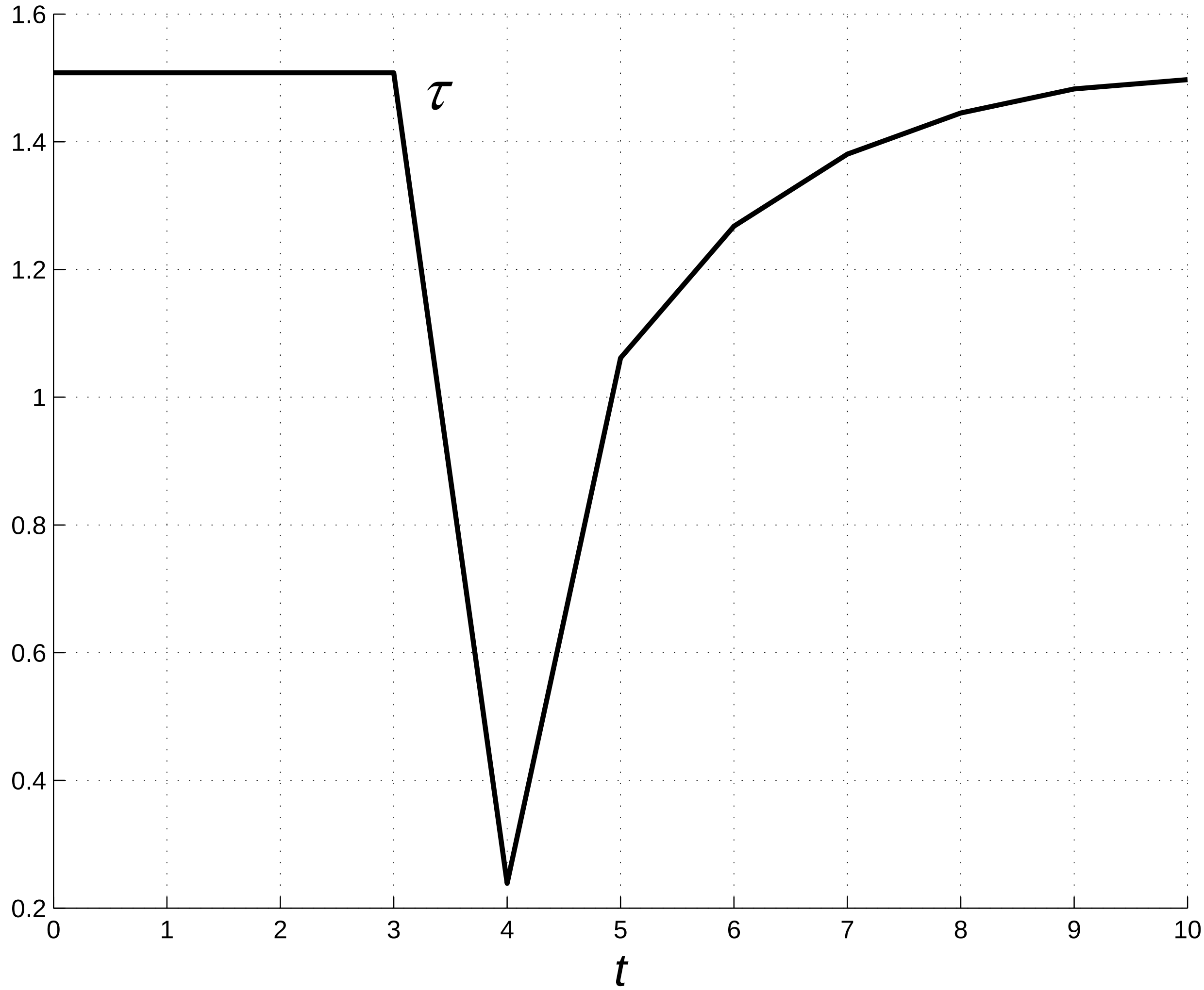
6.3 Optimal Policy

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.

Under the benchmark calibration, a planner finds it optimal to impose a tax on foreign borrowing in the amount of 1.5% in the high steady state. For example, if a borrower took on \$100 in foreign credit, the planner would impose a Pigouvian tax of \$1.5 per year. This magnitude of inflow taxation is within the range of policy measure that have recently been enacted by Brazil and other emerging economies.

If financial crisis occurs in the domestic economy, it is desirable to lower the tax in order to encourage investors to keep capital in the country. Figure 5 depicts the optimal macroprudential tax when a crisis has occurred in the country 1 in period 4. In the period the crisis occurs, the optimal level of the tax drops to zero percent. Over the ensuing periods,

Figure 5: Optimal tax rate with a single bust in country 1 in period 4



This figure reports the optimal level of macroprudential taxation in one country experiencing financial crisis in period 4 without any output shocks in the other country.

it rises progressively back to the steady state level.

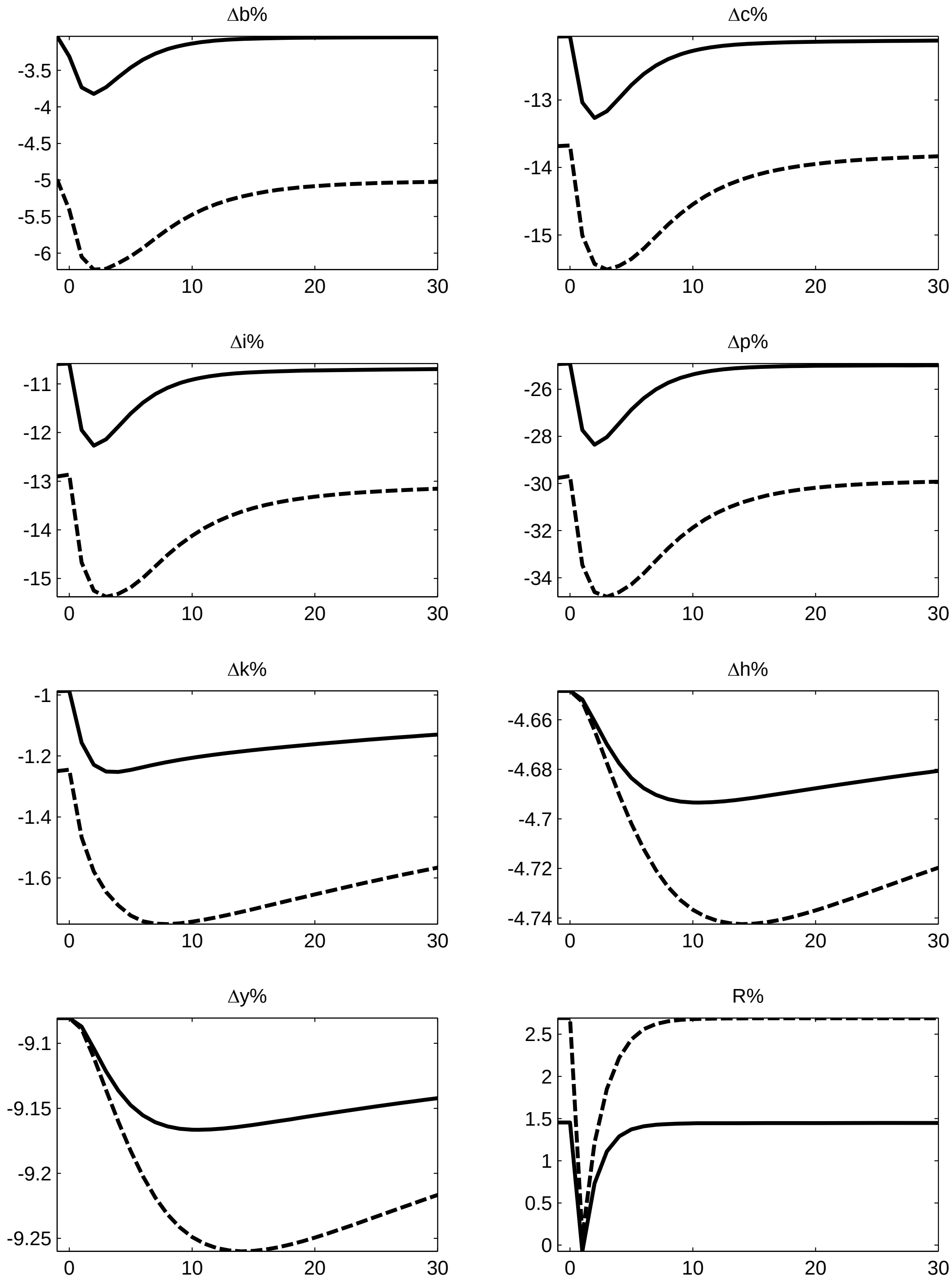
Figure 6 replicate the results of figure 4 given the optimal level of macroprudential taxation. The figure show the impact of an adverse shock in one country t period after an adverse shock has occurred in the other country. The dashed line represents the impact in the decentralized equilibrium and the solid line under a planner's optimal intervention. The tax on foreign borrowing mitigates the effects of an adverse shock on consumption from 13.7% to 12% in the high steady state of the world economy. When the country has experiences inflows of hot money in the aftermath of a crisis in another country, the tax reduces the impact of an adverse shock on consumption from 15.4% to 13.3%. Similarly, optimal taxation reduces the current account reversal from 5.0% to 3.0% in the high steady state of the world economy, and from 6.2% to 3.8% when a country has experienced inflows of hot money in the aftermath of a financial crisis somewhere else.

7 Conclusions

We have studied the consequences of serial financial crises in a two-country model with production and collateralized borrowing. Countries take on excessive debt and later suffer severe financial crisis with large current account reversals, decline in consumption, investment, output and asset prices. Private borrowers do not internalize that their decisions expose their country to such financial amplification effects creating credit externalities on other borrowers. A social planner can induce market participants to internalize these effects by imposing macroprudential regulation on capital inflows. This reduces macroeconomic volatility, financial fragility and improves welfare.

The model highlights a feature of international bond market when crises in one country push hot money into other countries making them more vulnerable to future adverse shocks. For example, one of the results is that an adverse shock that normally leads to 13.7% fall in consumption will cause 15.4% fall in consumption if a country has just experienced inflows

Figure 6: Optimal macroprudential taxation and impact of output shocks



This figure reports the impact of adverse output shocks on debt, consumption, investment, asset prices, capital stock, hours worked, output and interest rate if the domestic shock is delayed t periods after the other country experienced a financial crisis. The solid line represents the impact given the optimal policy intervention. For comparison, the dashed lines show the impact in the decentralized equilibrium.

of hot money. By imposing a capital inflow tax of 1.5%, these magnitudes can be reduced to 12.1% and 13.3% respectively.

Our findings suggest that adding investment channel is important for financial amplification. Investment lost during a credit crunch cannot be fully made up for during the ensuing recovery and hence has long-lasting detrimental effects on output. This implies that the welfare costs of financial crises are particularly large since they stretch over many periods.

A limitation of the present model is that it abstracts from long-run growth. Essentially I assume the booming economy is in the high steady state. Incorporating an endogenous growth would be a valuable extension.

Another avenue for further research could be modeling the foreign exchange rates to address policymaking concerns about appreciation during booms and sudden depreciation in busts when capital flows reverse. This mechanism is particularly important for emerging market economies who have taken excessive debts denominated in foreign currencies.

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Computational Appendix

Our numerical solution method is a two dimensional extension of the endogenous grid method of Korinek (2011*b*). Denote the vector of states of country i as $s_i = (b_i, k_i, z_i)$. The interest rate is a function of aggregate worldwide borrowing $R = R(b_1 + b_2)$ as given by (10). The problem is to obtain policy functions $c(s_1, s_2)$, $x(s_1, s_2)$, $p(s_1, s_2)$, $\lambda(s_1, s_2)$, $k'(s_1, s_2)$ and $b'_1(s_1, s_2)$. By symmetry, the latter function is identical to $b'_2(s_2, s_1)$.

The algorithm requires two nested loops to take full advantage of the endogenous grid method.

Outer Loop

At the beginning of iteration J in the outer loop, we start with the initial guesses $b'_J(s_1, s_2)$ and $k'_J(s_1, s_2)$ of policy functions $b'_1(s_1, s_2) = b'_2(s_2, s_1)$ and $k'_1(s_1, s_2) = k'_2(s_2, s_1)$. (The initial values can be set arbitrarily.)

Inner Loop

Each inner loop starts with the initial guess of policy functions $c_j(s_1, b'_2, k'_2)$, $x_j(s_1, b'_2, k'_2)$, $p_j(s_1, b'_2, k'_2)$ and $\lambda_j(s_1, b'_2, k'_2)$. (The initial values can be set arbitrarily or taken from the previous iteration of the outer loop). We calculate $\hat{c}(s_1, s_2) = c_j(s_1, b'_J(s_2, s_1), k'_J(s_2, s_1))$ and similarly for $\hat{x}$, $\hat{p}$ and $\hat{\lambda}$ by interpolation. In order to take advantage of the endogenous grid method, it is useful to perform our iterations over the grid (b'_1, k'_1, b'_2, k'_2) (since z'_1 and z'_2 are i.i.d.). For any pair (b'_1, b'_2), we calculate the world interest rate $R'(b'_1, b'_2) = R'(b'_1 + b'_2)$, which is obtained from lenders' optimality condition (10). Then we define

$$\mathbb{P}(b'_1, k'_1, b'_2, k'_2) \quad = \quad \beta E_{z'_1, z'_2} \Big\{ [\hat{c}(s'_1, s'_2) - \frac{\theta}{1+\gamma} h(s'_1)^{1+\gamma}]^{-\sigma} \cdot [\hat{p}(s'_1, s'_2) + \alpha y(s'_1) - \hat{x}(s'_1, s'_2)] \Big\}$$

where labor supply and output are defined as

$$\begin{aligned} h(s_1') &= \left(\frac{1-\alpha}{\theta} z_1' k_1'^{\alpha}\right)^{\frac{1}{\alpha+\gamma}} \\ y(s_1') &= z_1' k_1'^{\alpha} h(s_1')^{1-\alpha} = \frac{\theta}{1-\alpha} h(s_1')^{1+\gamma} \end{aligned}$$

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

$$\begin{aligned} \mathbb{C}^{\text{unc}}(b_1', k_1', b_2', k_2') &= \beta R'(b_1' + b_2') E_{z_1', z_2'} \left\{ [\hat{c}(s_1', s_2') - \frac{\theta}{1+\gamma} h(s_1')^{1+\gamma}]^{-\sigma} \right\} \\ p^{\text{unc}}(b_1', k_1', b_2', k_2') &= \frac{\mathbb{P}(b_1', k_1', b_2', k_2')}{\mathbb{C}^{\text{unc}}(b_1', k_1', b_2', k_2')} \\ \lambda^{\text{unc}}(b_1', k_1', b_2', k_2') &= 0 \end{aligned}$$

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

$$\begin{aligned} p^{\text{con}}(b_1', k_1', b_2', k_2') &= \frac{b_1'}{\phi R'(b_1' + b_2')} \\ \mathbb{C}^{\text{con}}(b_1', k_1', b_2', k_2') &= \frac{1}{1-\phi} \left[\frac{\mathbb{P}(b_1', k_1', b_2', k_2')}{p^{\text{con}}(b_1', k_1', b_2', k_2')} - \phi \mathbb{C}^{\text{unc}}(b_1', k_1', b_2', k_2') \right] \\ \lambda^{\text{con}}(b_1', k_1', b_2', k_2') &= 1 - \frac{\mathbb{C}^{\text{unc}}(b_1', k_1', b_2', k_2')}{\mathbb{C}^{\text{con}}(b_1', k_1', b_2', k_2')} > 0 \end{aligned}$$

The other variables in unconstrained and constrained branches can be found as follows

$$
\begin{aligned}
q^{\text{unc}|\text{con}}(b'_1,k'_1,b'_2,k'_2) &= \frac{p^{\text{unc}|\text{con}}(b'_1,k'_1,b'_2,k'_2)}{k'_1} \\
k^{\text{unc}|\text{con}}(b'_1,k'_1,b'_2,k'_2) &= \frac{k'_1}{1+\frac{\delta}{1-\frac{1}{\xi}}\{[q^{\text{unc}|\text{con}}(b'_1,k'_1,b'_2,k'_2)]^{\xi-1}-1\}} \\
x^{\text{unc}|\text{con}}(b'_1,k'_1,b'_2,k'_2) &= \delta k^{\text{unc}|\text{con}}(b'_1,k'_1,b'_2,k'_2)[q^{\text{unc}|\text{con}}(b'_1,k'_1,b'_2,k'_2)]^{\xi} \\
h^{\text{unc}|\text{con}}(z_1,b'_1,k'_1,b'_2,k'_2) &= \left[\frac{1-\alpha}{\theta}z_1[k^{\text{unc}|\text{con}}(b'_1,k'_1,b'_2,k'_2)]^{\alpha}\right]^{\frac{1}{\alpha+\gamma}} \\
y^{\text{unc}|\text{con}}(z_1,b'_1,k'_1,b'_2,k'_2) &= \frac{\theta}{1-\alpha}[h^{\text{unc}|\text{con}}(z_1,b'_1,k'_1,b'_2,k'_2)]^{1+\gamma} \\
c^{\text{unc}|\text{con}}(z_1,b'_1,k'_1,b'_2,k'_2) &= [\mathbb{C}^{\text{unc}|\text{con}}(b'_1,k'_1,b'_2,k'_2)]^{-\frac{1}{\sigma}}+\frac{1-\alpha}{1+\gamma}y^{\text{unc}|\text{con}}(z_1,b'_1,k'_1,b'_2,k'_2) \\
b^{\text{unc}|\text{con}}(z_1,b'_1,k'_1,b'_2,k'_2) &= y^{\text{unc}|\text{con}}(z_1,b'_1,k'_1,b'_2,k'_2)-c^{\text{unc}|\text{con}}(z_1,b'_1,k'_1,b'_2,k'_2) \\
&\quad -x^{\text{unc}|\text{con}}(b'_1,k'_1,b'_2,k'_2)+\frac{b'_1}{R'(b'_1+b'_2)}
\end{aligned}
$$

Concatenating constrained and unconstrained results allows us to obtain policy functions $c_{j+1}(s_1,b'_2,k'_2)$, $x_{j+1}(s_1,b'_2,k'_2)$, $p_{j+1}(s_1,b'_2,k'_2)$ and $\lambda_{j+1}(s_1,b'_2,k'_2)$. The steps are iterated until convergence is reached.

The root of the following equation yields $b'_1(s_1,b'_2,k'_2)$

$$
c(s_1,b'_2,k'_2)+x(s_1,b'_2,k'_2)+b_1-\frac{b'_1(s_1,b'_2,k'_2)}{R'(b'_1+b'_2)}=y(s_1)
$$

Once the loop is completed, we observe that the two functions $b'_1(s_1,b'_2,k'_2)$ and the symmetric $b'_2(s_2,b'_1,k'_1)$ can be combined to

$$
b'=b_1(s_1,b'_2(s_2,b'_1,k'_1),k'_2)
$$

Finding the root of this equation yields new functions $b'_{J+1}(s_1,s_2)$, $k'_{J+1}(s_1,s_2)$.