

MONETARY POLICY RESPONSES TO EXTERNAL SPILLOVERS IN EMERGING MARKET ECONOMIES

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Despite the remarkable progress made in many emerging and middle-income economies over the last few decades, the continuing liberalization in financial markets, and the integration into the global financial system, these countries remain highly vulnerable to real and financial shocks coming from the U.S. and other advanced economies. Particularly in the aftermath of the financial crisis, emerging economies have been subject to rapid buildups and reversals of international capital flows and large real exchange rate fluctuations. This experience is partially responsible for a new debate on the relevance of the open economy policy ‘trilemma’ as applied to emerging market economies (Rey, 2013, 2015). If the standard toolkit of macroeconomic policy levers is not adequate for emerging market economies in a global financial system with damaging macroeconomic spillovers, perhaps these countries need to slow down or reverse the momentum of financial openness in order to manage their economies.

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In particular, if an emerging economy is exposed to large spillovers from advanced economy shocks, having a flexible exchange rate may provide little policy independence, and the best option for shielding the economy from damage may be to employ controls on international capital inflows.

Our paper is motivated by this recent debate. We follow a theoretical approach to modeling financial crises in emerging market economies, and combine this with the standard analysis of monetary policy from the New Keynesian literature.¹ Our contribution is to blend these two frameworks together, in order to investigate the extent to which standard prescriptions for monetary policy are muted or circumscribed in small economies with financial frictions and endogenous financial crises. In particular, we ask to what degree the exchange rate system is important in dealing with financial crises, and whether an active or an accommodating monetary policy should be used, in contrast to a simple inflation-targeting policy as is prescribed for advanced economies. We also ask whether monetary policy should operate in a ‘macro-prudential’ fashion, in an attempt to reduce the risk of future financial crises by leaning against the wind. Finally, we explore how the monetary and exchange rate system itself effects the frequency and severity of financial crises.

As we mentioned, our model represents a combination of two main approaches. The first one, championed by Mendoza and others,² models financial crises as occurrences of ‘occasionally binding collateral constraints’, in which a financial crisis leads to a collapse in asset prices and further tightening of constraints through a financial accelerator effect. The second approach is the standard open-economy New Keynesian model.³ The synergies involved in blending these two frameworks allow us to provide a comprehensive evaluation of the role of monetary policy in the incidence of and response to emerging market financial crises.

We introduce a simple small open economy model with sticky prices and collateral constraints which depend on asset prices, where shocks to world interest rates or leverage limits may throw the economy into a crisis. We compare three different monetary systems within this

1. Our paper reviews and extends some material from Devereux and Yu (2016), and Devereux, Young, and Yu (2015).

2. See, e.g., Bianchi and Mendoza (2010).

3. See, e.g., Gali and Monacelli (2005).

model: a flexible exchange-rate system with pure inflation targeting, an optimal discretionary monetary policy with flexible exchange rates, and a strict exchange rate peg. We find that, when the model is calibrated to emerging economy data, there is little difference between the three systems in the absence of financial crises. But, in a crisis, an exchange rate peg does much worse than the rest, since it requires a costly deflation and a large spike in real interest rates. Moreover, a pegged exchange rate puts severe constraints on the range of external debt over which the economy is vulnerable to a crisis.

During 'normal times,' i.e., outside of crises, the model implies that macro volatility is sufficiently contained and that there is no need for a large real exchange rate adjustment. A substantial part of adjustment can take place through movements in the price level, since, while prices are sticky in the model, the price level can evolve over time through price adjustment. But in crisis times, the economy requires a large and rapid real exchange rate depreciation. In the absence of nominal flexibility, this is very costly, since it involves a large deflation and a substantial increase in the output gap.

The comparison between the policy with pure inflation targeting and an optimal time-consistent monetary policy is far less extreme. We find that there is little difference between these two monetary policies, both of which actively exploit the flexibility of the nominal exchange rate. Outside of crises, the optimal discretionary policy in fact follows a pure inflation target. In a crisis, the optimal policy is more expansionary, but the net effect of this relative to pure inflation targeting is minimal.

As a corollary, this model implies that there is no macro-prudential role for monetary policy. An optimal monetary policy does not adjust to the likelihood of future crises, but adjusts only upon the occurrence of a crisis. While this feature is somewhat specific to the form of the financial friction facing borrowers in our model, it is noteworthy, nonetheless, that the possibility of large periodic sudden stops in capital flows does not necessarily justify a departure from an inflation-targeting monetary rule.

Different monetary stances also affect the frequency of crises. Surprisingly, we find that crises may be less frequent in a (successful) pegged exchange rate regime. This is due to the fact that pegged exchange rates tend to have less volatile real exchange rates and, on balance, tend to incur less external liabilities due to a higher level of precautionary current account surpluses.

1. RELATED LITERATURE

Our paper is related to a growing recent literature along several dimensions, which we decompose as described below.

1.1 Macprudential Capital Controls

Since the global financial crisis, there has been a surge of interest in capital flow regulations. Bianchi (2011) studies an endowment economy with tradable and non-tradable sectors. Private agents do not internalize the effects of their borrowing on asset prices in a crisis, which leads to an *ex-ante* overborrowing. Bianchi and Mendoza (2010) develop state-contingent capital inflow taxes to prevent overborrowing. This state-contingent taxation can be understood as Pigouvian taxation, as in Jeanne and Korinek (2010). Schmitt-Grohe and Uribe (2012) investigate a model with downward wage rigidity, to explain the large and protracted slump in the Eurozone. On the other hand, when there exist *ex-post* adjustments of production between tradable and non-tradable sectors, private agents may engage in underborrowing, as shown in Benigno, Chen, Otrok, Rebucci, and Young (2013).

Schmitt-Grohe and Uribe (2016b) study a Bianchi (2011)-type model and optimal capital controls from the perspective of boom-bust cycles, rather than the narrow-defined crisis scenarios. They show that over-borrowing and amplification are small, and that optimal capital control policy is not countercyclical and, hence, not macroprudential. Their model differs from ours in a number of dimensions, but one of the key distinctions is that they focus on a borrowing constraint which depends upon current relative non-traded goods prices, while we posit a collateral constraint which depends on expected future prices of capital as in Kiyotaki and Moore (1997).

Korinek (2011), Lorenzoni (2015), and Engel (2015) provide comprehensive reviews on borrowing and macroprudential policies during financial crises. As regards the description of optimal policy, Bianchi and Mendoza (2013) explore a time-consistent macroprudential policy. Devereux, Young, and Yu (2015) focus on time-consistent monetary and capital control policies in a flexible exchange rate regime. Capital controls, in their case, are welfare-reducing, because of a key time consistency involved in the valuation of collateral.

1.2 Monetary Policy and Effects of Capital Controls on Monetary Policy

Rey (2013), and Passari and Rey (2015) show that volatile capital flows can lead to substantial economic dislocation, even under a flexible exchange rate regime, while Georgiadis and Mehl (2015) still support the view of the traditional ‘trilemma’ case in favor of floating exchange rates. Based on the experience of the Eurozone, Schmitt-Grohe and Uribe (2016a) show that various types of taxes can be used to reduce the severity of financial crisis if the nominal exchange rate cannot be adjusted. Fornaro (2013a) extends Bianchi’s model (Bianchi, 2011) to a Gali-Monacelli type of small open economy (Gali and Monacelli, 2005) and shows that debt deleveraging may generate a world-wide recession in a monetary union. In a similar vein, Fornaro (2013b) investigates the trade-off between price and financial stability in a small open economy with sticky wages and credit constraints. Building upon Schmitt-Grohe and Uribe (2016a), Ottonello (2015) studies exchange rate policy and capital controls in a small open economy. Policymakers in his model have to balance the tension between unemployment and value of collateral caused by exchange rate movements. In a similar vein but in a different framework, Devereux, Young, and Yu (2015) show that monetary policy should stabilize domestic inflation in normal times, but should dramatically deviate from the target in sudden stop scenarios in order to stimulate domestic aggregate demand. Liu and Spiegel (2015) explore optimal capital controls and monetary policy in a small open economy around its deterministic steady state. They focus on imperfect asset substitutability between domestic and foreign bonds. Optimal policy is to stabilize the domestic economy and to increase risk sharing across borders.

The most related works are Farhi and Werning (2012, 2013). They explore optimal capital controls and monetary policy in a Gali-Monacelli type of small open economy model and illustrate that capital controls can help regain monetary autonomy in a fixed exchange rate regime and work as terms of trade manipulation in a flexible exchange rate regime. They make use of risk premium shocks to break the uncovered interest rate parity condition. Our work is quite different from theirs. First, we investigate a fully-fledged small open-economy New Keynesian model with occasionally binding collateral constraints. Risk premia are endogenous in our model. Second, our model can capture both the normal time business cycle properties and

also sudden stop scenarios. A policy affects not only the variability of macroeconomic variables but, more importantly, it changes the first moment (mean) of variables.

1.3 Currency Manipulation and Currency Wars

It has long been recognized that even in a small economy, monetary authorities can manipulate their currency in favor of domestic households. Costinot, Lorenzoni, and Werning (2014) show how capital controls and foreign exchange interventions can be used as intertemporal terms of trade manipulation. The choice of an exchange rate regime may reflect the intention of currency manipulation, as in Hassan, Mertens, and Zhang, 2015. Market frictions and incompleteness of policy tools are also roots of currency manipulation and even currency wars (Korinek, 2015). Our paper is related to this literature in the sense that monetary and fiscal authorities may have incentives to manipulate the value of domestic currency to enhance domestic welfare at the expense of the rest of the world. But, as described below, we assume that fiscal measures are in place so as to avoid the use of monetary or capital control policy for terms of trade manipulation.

The paper is organized as follows: Section 2 describes the details of the small open economy model. Section 3 discusses the calibration assumption. Section 4 briefly explains the solution method. Section 5 presents the main results. Section 6 presents some brief conclusions.

2. THE MODEL

All the analysis in this paper will be based on a prototype model of a small open economy. The baseline model structure is mostly taken from Devereux, Young, and Yu (2015), which in turn builds upon Cespedes, Chang, and Velasco (2004), and Mendoza (2010). In the domestic economy, we assume that there exist infinitely lived firm-households with a unit measure. Households consume, invest in domestic capital and foreign bonds, and supply labor. Domestic firms are owned by households. International financial markets are incomplete. Domestic households trade assets across borders only in foreign currency denominated non-state contingent bonds. There are two types of domestic stand-in producers: competitive wholesale goods producers and monopolistically competitive final goods producers.

The latter assumption allows for sticky prices. Wholesale producers combine imported intermediate inputs, domestic labor, and physical capital in competitive factor markets with production technology as follows:

$$M_t = A_t Y_{F,t}^{\alpha_F} L_t^{\alpha_L} K_t^{\alpha_K}, \tag{1}$$

with $\alpha_F + \alpha_L + \alpha_K \leq 1$. M_t denotes wholesale good production, A_t is a country-specific exogenous technological shock, $Y_{F,t}$ is imported intermediate inputs, L_t is labor demand, and K_t is physical capital.

Imported intermediate inputs are differentiated into a unit mass of individual imported varieties. Since prices of intermediate inputs in the rest of world are exogenously given, we can abstract away from the pricing decision of foreign intermediate suppliers. We assume that foreign currency denominated prices of all intermediate varieties are identical and normalized to unity.

As is further described below, wholesale goods produced in the domestic economy are themselves combined to produce a final consumption good which is sold to both domestic households and foreign consumers. Let us assume that the foreign demand function for the domestic consumption composite, X_t , can be written as

$$X_t = \left(\frac{P_t}{E_t P_t^*} \right)^{-\rho} \zeta_t^*, \tag{2}$$

where P_t is the price of the domestic composite good, and E_t is the nominal exchange rate (price of foreign currency). The term ζ_t^* stands for foreign demand, while $\rho > 1$ is the elasticity of substitution between imports and locally produced goods in the foreign consumption basket. The share of expenditures in the foreign country (the rest of world) on imports from the domestic country is assumed to be negligible, and can thus be ignored as a component of the foreign CPI. Hence, we normalize the consumer price index in the foreign country to unity $P_t^* = P_{F,t}^*(i) = 1$.

2.1 Domestic Firm-Households

In the domestic economy, the representative infinitely lived firm-household has preferences given by

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t, l_t), \tag{3}$$

where E_0 represents the expectation conditional on information up to date 0. We assume that the household is impatient relative to the rest of the world, so that the subjective discount factor is constrained by $\beta R_{t+1}^* < 1$. This ensures that in a deterministic steady state, the small economy remains a net debtor. Current utility function takes a GHH (Greenwood, Hercowitz, and Huffman, 1988) form.⁴

$$U(c_t, l_t) = \frac{\left(c_t - \chi \frac{l_t^{1+\nu}}{1+\nu} \right)^{1-\sigma}}{1-\sigma}. \quad (4)$$

Similar to Mendoza (2010), households borrow from abroad to finance both imported intermediate inputs and final goods consumption. All borrowing is denominated in foreign currency. In addition, total borrowing from abroad requires physical capital k_{t+1} as collateral. There are many approaches to rationalizing such a constraint. The most immediate motivation is to assume the presence of agency costs associated with imperfect contract enforcement. Hence the collateral (or borrowing) constraint can be written as

$$\vartheta(1 + \tau_{N,t})Y_{F,t} - B_{t+1}^* \leq \kappa_t E_t \left\{ \frac{Q_{t+1}k_{t+1}}{E_{t+1}} \right\}, \quad (5)$$

where B_{t+1}^* stands for domestic household's foreign currency bond holdings at the end of period t , $\tau_{N,t}$ is an import tax, ϑ measures the fraction of imported inputs $(1 + \tau_{N,t})Y_{F,t}$ which is financed in advance, and Q_{t+1} is the nominal capital price in domestic currency.⁵ The parameter κ_t captures the maximal loan-to-value ratio according to Kiyotaki and Moore (1997). We assume that this is stochastic and follows a random process which will be described below.

4. This form of preference makes the computational procedure easier, but does not play a key role in the qualitative analysis.

5. The import tax $\tau_{N,t}$ is applied for technical reasons. The foreign demand function (2) implies that the small economy collectively has market power over its export good. The import tax is set at the steady state value which ensures that this market power is maximized at the 'optimal tariff' level. This is done so as to eliminate the incentive for the monetary policymaker to conflate the policy problem associated with nominal rigidities and the collateral constraint with the exploitation of market power in the terms of trade of the economy. We note that this constraint is not developed from first principles, although it can be given a micro-founded rationale (see Devereux, Young, and Yu, 2015). It would be interesting to explore a deeper theory of financing constraints which allowed for a role for financial institutions (e.g., Holmstrom and Tirole, 1997) within a model of occasional crises.

Households own domestic firms equally. Each household makes identical decisions in a symmetric equilibrium. The representative firm-household faces the following budget constraint

$$P_t c_t + Q_t k_{t+1} + \frac{B_{t+1}}{R_{t+1}} + \frac{B_{t+1}^* E_t}{R_{t+1}^*} \leq W_t l_t + k_t (R_{K,t} + Q_t) + B_t + B_t^* E_t + T_t \quad (6)$$

$$+ [P_{M,t} M(Y_{F,t}, L_t, K_t) - (1 + \tau_{N,t}) Y_{F,t} E_t - W_t L_t - R_{K,t} K_t] + D_t.$$

The left-hand side of the this constraint represents domestic consumption expenditure, $P_t c_t$; capital purchases, $Q_t k_{t+1}$; domestic bond holdings, B_{t+1}/R_{t+1} ; and bond holdings in foreign currency, $B_{t+1}^* E_t/R_{t+1}^*$. The right-hand side of (6) consists of labor income, $W_t l_t$; gross return on capital, $k_t (R_{K,t} + Q_t)$; gross return on domestic currency bond holdings, B_t , and foreign bond holdings, $B_t^* E_t$; lump-sum transfers from government, T_t ; profits from wholesale good producers, $P_{M,t} M_t - (1 + \tau_{N,t}) Y_{F,t} E_t - W_t L_t - R_{K,t} K_t$; and profits from the rest of the domestic economy, D_t . The wholesale good production M_t is given by equation (1). As in Bianchi and Mendoza (2013), we assume that working capital incurs no interest rate payments.

Let $\mu_t e_t$ be the Lagrange multiplier for the borrowing constraint (5). A lower case price variable denotes a real price, so that $q_t = Q_t/P_t$, $w_t = W_t/P_t$. The consumer price index inflation rate is defined as $\pi_t = P_t/P_{t-1}$. The real exchange rate (which in our case is also the terms of trade) is $e_t = E_t P_t^*/P_t$. Higher e_t implies a real exchange rate depreciation.

We may summarize the household's optimality decisions as those where the optimal labor supply decision satisfies

$$w_t = \chi_t l_t^\nu. \quad (7)$$

With these preferences, household's labor supply is independent of wealth effects.

The optimality conditions for the household's choice of capital is given by the Euler equation

$$q_t = \mu_t \kappa_t E_t \left\{ \frac{q_{t+1} e_t}{e_{t+1}} \right\} + E_t \left\{ \beta \frac{U_c(t+1)}{U_c(t)} (r_{K,t+1} + q_{t+1}) \right\}. \quad (8)$$

The benefit of holding one more unit of domestic capital comes from the increased collateral value of capital, which relaxes the borrowing constraint in the case $\mu_t > 0$, as well as the usual direct return on

capital from the rental rate plus the future price, discounted by the household's stochastic discount factor, where $U_c(t)$ stands for the marginal utility of consumption.

The household's choice of domestic bonds is unaffected by the collateral constraint, and described by

$$1 = E_t \left\{ \beta \frac{U_c(t+1) R_{t+1}}{U_c(t) \pi_{t+1}} \right\}. \quad (9)$$

Finally, the choice of foreign currency bonds leads to the following condition:

$$1 = \mu_t R_{t+1}^* + E_t \left\{ \beta \frac{U_c(t+1) e_{t+1}}{U_c(t) e_t} R_{t+1}^* \right\} \quad (10)$$

As in the capital Euler equation, the benefit of holding an additional unit of the foreign currency bond is enhanced if the collateral constraint (5) is binding. The term $\mu_t R^*$ represents an 'external finance premium,' indicating that the cost of borrowing abroad is effectively higher than the world cost of funds when the economy is constrained by (5). The size of the external finance premium represents a measure of the degree of financial frictions in the domestic economy. As we see below, the external finance premium will depend in a critical way upon the monetary rule and the exchange rate regime.

We note that the combination of (9) and (10) implies that uncovered interest rate parity will not hold in this model when $\mu_t > 0$, even up to a first order approximation. Moreover, the external finance premium will vary according to the degree to which the constraint binds. As we show below, this external finance premium may differ systematically between alternative monetary policy regimes. In particular, we will show that in a crisis, domestic interest rates may be much higher in a pegged exchange rate regime than under a floating regime.

The household-firm's choice of imported inputs, labor and capital are expressed as

$$p_{M,t} \frac{\alpha_F M_t}{Y_{F,t}} = e_t (1 + \vartheta \mu_t) (1 + \tau_{N,t}), \quad (11)$$

$$p_{M,t} \frac{\alpha_L M_t}{L_t} = w_t \quad (12)$$

$$p_{M,t} \frac{\alpha_K M_t}{K_t} = r_{K,t}. \quad (13)$$

where w_t denotes the cost of labor.

Note that condition (11) implies that a binding collateral constraint increases the effective costs of imported intermediate goods for the firm. Thus, as in Mendoza (2010), there is a direct negative effect of a binding constraint on the firm's production and employment of labor.

The complementary slackness condition related by (5) is written as

$$\mu_t \left[\kappa_t E_t \left(\frac{q_{t+1} k_{t+1}}{e_{t+1}} \right) + b_{t+1}^* - \vartheta Y_{F,t} (1 + \tau_{N,t}) \right] = 0, \quad (14)$$

where we have replaced nominal bond B_{t+1}^* with real bonds $b_{t+1}^* = B_{t+1}^* / P_t^*$.

2.2 Final Good Producers

There is a continuum of monopolistically competitive final good producers with measure 1. Each producer differentiates wholesale goods into a variety of final goods, where each variety is an imperfect substitute for the other varieties, thus implying that final good producers have monopoly power. Varieties are then aggregated into a consumption composite, which has a constant elasticity of substitution (Dixit and Stiglitz, 1977) form of

$$Y_t = \left(\int_0^1 (Y_t(i))^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}},$$

where Y_t is total demand for consumption composites and $Y_t(i)$ is demand for variety i in period t . The parameter $\theta > 1$ represents the elasticity of substitution between varieties. Let $P_t(i)$ be the nominal price of variety $Y_t(i)$. Cost minimization implies

$$P_t = \left(\int_0^1 (P_t(i))^{1-\theta} di \right)^{\frac{1}{1-\theta}},$$

and the demand for variety $Y_t(i)$,

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\theta} Y_t. \quad (15)$$

Each variety producer makes use of a linear technology through the use of the wholesale good as an input

$$Y_t(i) = M_t(i). \quad (16)$$

Firms set prices in local currency and can reset their prices each period, but resetting price incurs a cost. We follow Rotemberg (1982) in positing a quadratic price adjustment cost. Firm i 's profits in each period equal total revenues net of wholesale prices and of price adjustment costs. These can be written as

$$D_{H,t}(i) \equiv (1 + \tau_H)P_t(i)Y_t(i) - P_{M,t}Y_t(i) - \phi\left(\frac{P_t(i)}{P_{t-1}(i)}\right)Y_tP_t.$$

Here τ_H denotes a subsidy rate by the fiscal authority so as to offset the monopoly power of price setters. Following Varian (1975) and Kim and Ruge-Murcia (2009), we assume an asymmetric price adjustment function $\phi\left(\frac{P_t(i)}{P_{t-1}(i)}\right)$ given by

$$\phi\left(\frac{P_t(i)}{P_{t-1}(i)}\right) \equiv \phi_P \frac{\exp\left(\gamma\left(\frac{P_t(i)}{P_{t-1}(i)} - \pi\right)\right) - \gamma\left(\frac{P_t(i)}{P_{t-1}(i)} - \pi\right) - 1}{\gamma^2}.$$

Here π is the inflation target. In the cost function $\phi(\cdot)$, ϕ_p characterizes the basic Rotemberg price adjustment cost and γ captures the asymmetry of the price adjustment cost. When $\gamma < 0$, the price adjustment displays a pattern of downward rigidity.

Firm i faces the following problem:

$$\max_{\{P_t(i), Y_t(i)\}} E_h \left(\sum_{t=h}^{\infty} \Lambda_{h,t} \frac{P_h}{P_t} D_{H,t}(i) \right),$$

subject to demand for variety i (15) and production technology (16). The household's stochastic discount factor used by the firm is given by $\Lambda_{h,t} = \beta^{t-h} U_c(t) / U_c(h)$ with $h \leq t$.

In a symmetric equilibrium, all firms choose the same price, $P_t(i) = P_t$. As a result, the supply of each variety will be identical to $Y_t(i) = Y_t$ in equilibrium. The optimality condition for price-setting can be simplified as

$$\begin{aligned} Y_t \left[(1 + \tau_H) - \theta(1 + \tau_H - p_{M,t}) \right] - \phi_P Y_t \pi_t \frac{\exp(\gamma(\pi_t - \pi)) - 1}{\gamma} + \\ E_t \left[\Lambda_{t,t+1} \phi_P \pi_{t+1} Y_{t+1} \frac{\exp(\gamma(\pi_{t+1} - \pi)) - 1}{\gamma} \right] = 0. \end{aligned} \quad (17)$$

Real profits from intermediate producers are

$$d_{H,t} \equiv \frac{D_{H,t}}{P_t} = (1 + \tau_H)Y_t - p_{M,t}Y_t - \phi(\pi_t)Y_t \quad (18)$$

$$= Y_t [(1 + \tau_H) - p_{M,t} - \phi(\pi_t)]$$

with

$$\phi(\pi_t) = \phi_p \frac{\exp(\gamma(\pi_t - \pi)) - \gamma(\pi_t - \pi) - 1}{\gamma^2}.$$

In the absence of price adjustment costs, $\phi_p = 0$ and with the appropriate production subsidy $\tau_H = 1 / (\theta - 1) > 0$, production markets are frictionless, so that $p_{M,t} = 1$.

Markets clear at the end of each period, and we impose that $l_t = L_t$, $c_t = C_t$. We are assuming that domestic bonds are only held by domestic agents. Abstracting away from government bond issuance, this means that $b_{t+1} = 0$ in the aggregate. Also, in the aggregate, the capital stock is fixed. We normalize then so that $K_{t+1} = k_{t+1} = 1$. Profits from final good producers yield $d_t = d_{H,t}$. The wholesale goods market clearing condition reads

$$\int_0^1 Y_t(i) di = \int_0^1 M_t(i) di = M_t. \quad (19)$$

The composite final good is either consumed by domestic households or exported to the rest of world

$$Y_t [1 - \phi(\pi_t)] = C_t + X_t. \quad (20)$$

2.3 Government Policy

The government doesn't issue bonds, but makes lump-sum transfers to domestic households

$$T_t = -\tau_H Y_t P_t - \frac{\tau_{c,t} b_{t+1}^* e_t}{R_{t+1}^*} P_t + \tau_{N,t} Y_{F,t} e_t P_t. \quad (21)$$

As noted above, we also assume that the government sets a production subsidy τ_H to offset the monopoly power of price setting. The central bank conducts monetary policy under either a fixed or a flexible exchange rate regime. Under the latter, monetary policy takes

the form of either a strict inflation-targeting policy or an optimal, welfare-maximizing monetary policy rule. Under either the fixed exchange rate regime or the strict inflation-targeting regime, the monetary rule can be defined by⁶

$$R_{t+1} = R \left(\frac{\pi_t}{\pi} \right)^{\alpha_\pi} \left(\frac{Y_t}{Y} \right)^{\alpha_Y} \left(\frac{e_t}{e} \right)^{\alpha_e}. \quad (22)$$

A variable without a superscript denotes the value at the deterministic steady state. The response coefficients $\alpha_\pi > \alpha_Y > 0$ and are interpreted in the usual manner. In the fixed exchange rate regime, domestic inflation must equal the sum of foreign inflation and the change in the real exchange rate, so that

$$\pi_t = \frac{e_{t-1}}{e_t} \pi_t^* = \frac{e_{t-1}}{e_t}. \quad (23)$$

Note that the fixed exchange rate regime implies that inflation has a backward-looking element, depending on the lagged real exchange rate.

2.4 Optimal Monetary Policy

As an alternative to the strict inflation-targeting policy on the one hand, and the exchange rate peg on the other, we will explore the case where the monetary authority solves a Ramsey planner's problem to maximize a representative household's lifetime utility. The optimal policy is implemented only by a monetary policy instrument; e.g., the nominal interest rate. Under optimal monetary policy, we must implicitly assume a regime of flexible exchange rates. In addition, we will focus on the time-consistent optimal policy under discretion and look for a Markov perfect equilibrium. This is a situation where the current planner (or monetary authority) takes as given the decisions of future planners, but still internalizes how the choices of future planners will depend on the future debt level b_{t+1}^* which is implicitly chosen by the current planner.

6. Note that the change in the nominal exchange rate is a function of the change in the real exchange rates and inflation, $\varepsilon_t/\varepsilon_{t-1} = \pi_t e_t/e_{t-1}$. Therefore, stabilizing nominal exchange rates and inflation is equivalent to stabilizing both inflation and the real exchange rate.

Let the value function for a representative domestic firm-household be $V(b_t^*, Z_t)$, where Z_t represents the set of exogenous state variables. Under the time-consistent Ramsey optimum, the problem faced by the monetary authority can be represented as

$$V(b_t^*, Z_t) = \max_{\{\Xi\}} U(\tilde{C}_t) + \beta E_t V(b_{t+1}^*, Z_{t+1}), \text{ with } \tilde{C}_t \equiv C_t - \chi \frac{L_t^{1+\nu}}{1+\nu}$$

with

$$\Xi \equiv \{L_t, C_t, Y_t, Y_{F,t}, b_{t+1}^*, q_t, \mu_t, r_{K,t}, e_t, p_{M,t}, \pi_t\},$$

subject to the set of competitive equilibrium conditions.⁷

2.5 Aggregate Market Clearing

Combining the firm-households' budget constraints (6) with the relevant market clearing conditions and taxation policy (21), yields the country level resource constraint

$$C_t + \left(\frac{b_{t+1}^*}{R_{t+1}^*} - b_t^* \right) e_t = Y_t (1 - \varphi(\pi_t)) - e_t Y_{F,t}. \quad (24)$$

Equivalently, condition (24) implies that trade surpluses are used to finance external debt

$$X_t - e_t Y_{F,t} = \left(\frac{b_{t+1}^*}{R_{t+1}^*} - b_t^* \right) e_t. \quad (25)$$

2.6 A Recursive Competitive Equilibrium

A recursive competitive equilibrium consists of a sequence of allocations $\{L_t, C_t, Y_{F,t}, Y_t, K_{t+1}, b_{t+1}^*\}$, and a sequence of prices $\{w_t, q_t, \pi_t, \mu_t, r_{K,t}, e_t, p_{M,t}\}$, for $t = \dots, 0, 1, 2, \dots$, given production subsidy τ_H , import tax $\tau_{N,t}$, capital inflow tax $\tau_{c,t}$ and monetary policy R_{t+1} , such that (a) allocations solve households' and firms' problems given prices and public policies and (b) prices clear corresponding markets.

7. A more complete account of this optimal monetary policy problem in a related context is given in Devereux, Young, and Yu (2015).

3. CALIBRATION

The model period is one quarter. Table 1 lists parameter values in the baseline model. The preference parameters are quite standard and taken from the literature. In normal times without a binding constraint, optimal inflation equals its target. Therefore, domestic nominal interest rates reflect domestic real interest rates. We set the subjective discount factor $\beta = 0.975$, in line with the literature for emerging economies (Uribe and Yue, 2006; Aguiar and Gopinath, 2007), thus implying an annual real interest rate of 10%. Relative risk aversion is set to $\sigma = 2$ and the inverse of Frisch labor supply elasticity is $\nu = 1$.

The leverage shock κ_t determines the borrowing capacity in a country. We take a two-state Markov chain to capture the leverage shock: $\kappa_L = 0.35$ and $\kappa_H = 0.5$. These two states are consistent with the leverage change from pre-crisis period to crisis period for U.S. nonfinancial corporations (Graham, Leary, and Roberts, 2015) and the corporate leverages in Asian emerging economies (IMF, 2014).⁸ The transition matrix is given by

$$\Pi_l = \begin{bmatrix} p_{L,L} & 1 - p_{L,L} \\ 1 - p_{H,H} & p_{H,H} \end{bmatrix}.$$

We set $p_{L,L} = 0.775$ and $p_{H,H} = 0.975$ such that the duration of a high leverage regime equals quarters and the unconditional probability of a low leverage regime is (Bianchi and Mendoza, 2013), thus implying that a typical leverage crisis will happen every ten years.

8. Mendoza (2010) uses a similar leverage $\kappa_t = 0.2$ and $\kappa_t = 0.3$ in his analysis.

Table 1. Parameter values

<i>Parameter</i>		<i>Value</i>
<i>Preference</i>		
β	Subjective discount factor	0.975
σ	Relative risk aversion	2
ν	Inverse of Frisch labor supply elasticity	1
χ	Parameter in labor supply	0.4
<i>Production</i>		
α_F	Intermediate input share in production	0.13
α_L	Labor share in production	0.57
α_K	Capital share in production	0.03
ϑ	Share of working capital	1.3
ϕ_P	Price adjustment cost	76
γ	Asymmetry of price adjustment cost	-100
θ	Elasticity of substitution among imported varieties	10
ρ	Elasticity of substitution in the foreign countries	10
ζ	Steady state of foreign demand shock	0.101
R^*	Steady state of world interest rate	1.015
A	Steady state of TFP shock	1
ρ_A	Persistence of TFP shocks	0.95
σ_A	Standard deviation of TFP shocks	0.008
ρ_R	Persistence of foreign interest rate shocks	0.6
σ_R	Standard deviation of foreign interest rate shocks	0.00623
$p_{H,H}$	Transitional probability of high leverage to high leverage	0.975
$p_{L,L}$	Transitional probability of low leverage to low leverage	0.775
<i>Policy variables</i>		
$\alpha_\pi, \alpha_Y, \alpha_e$	Coefficients in the Taylor rule	
τ_H	Subsidy to final goods producers	$\frac{1}{\theta-1}$
$\tau_{N,t}$	Gross subsidy to exports	$\frac{1}{\rho-1}$

Parameters in the production function are set to match imports share (15% of GDP, see Hanson, 2012), labor share (65% of GDP, see Mendoza, 2010) and the external debt-GDP ratio (40%) in emerging economies before the global financial crisis.⁹ Given the leverage specification above and relevant ratios, we set $\alpha_F = 0.13$, $\alpha_L = 0.57$ and $\alpha_K = 0.03$. Parameter ϑ is set to 1.3, thus implying a share of working capital of 20% of GDP (Mendoza, 2010).¹⁰ The equilibrium labor supply in normal times (without credit constraints) is normalized to be 1, which implies that $\chi = 0.4$.

Nominal rigidity is introduced through a Rotemberg price adjustment cost. Price adjustment takes around four quarters. We set $\phi_p = 76$ as in Aruoba and Schorfheide (2013), and assume a small downward price rigidity $\gamma = -100$.¹¹ Following the New Keynesian literature (Christiano, Eichenbaum, and Evans, 2005; Gali, 2015), we set the elasticity of varieties in both domestic and foreign consumption baskets as $\theta = \rho = 10$, thus implying a price markup of 11%.

The real exchange rate is normalized to be 1 in a deterministic steady state when the collateral constraint binds, which requires $\zeta_t^* = 0.101$. Domestic productivity and foreign interest rate, each follows an AR(1) process:

$$\ln(A_{t+1}) = (1 - \rho_A) \ln(A) + \rho_A \ln(A_t) + \varepsilon_{A,t+1}$$

$$\ln(R_{t+1}^*) = (1 - \rho_R) \ln(R^*) + \rho_R \ln(R_t^*) + \varepsilon_{R,t+1}$$

where mean productivity is normalized to be 1, $A = 1$, and the world quarterly real interest rate, $R^* = 1.015$ (Mendoza, 2010). We assume that the local productivity shock is uncorrelated with the global

9. Data from World Development Indicators show that, just before the onset of the global financial crisis, many emerging economies accumulated a large amount of external debt stocks, around 40% of their gross national income. Data source: World Development Indicators with indicator code: DT.DOD.DECT.GN.ZS.

10. Note that ϑ captures the role of working capital only when credit constraints bind. This value is higher than Mendoza (2010) and Bianchi and Mendoza (2013), but is consistent with Uribe and Yue (2006).

11. The Rotemberg price adjustment cost relates to the Calvo price stickiness via $\phi_p = \alpha(\theta - 1) / ((1 - \alpha)(1 - \alpha\beta))$ in an economy without collateral constraints (Khan, 2005). $1 - \alpha$ measures the probability of Calvo style price adjustment in each period. Empirical evidence shows that prices rise faster than they fall (Peltzman, 2000) and small price increases occur more frequently than small price decreases for price changes (Chen, Levy, Ray and Bergen, 2008).

liquidity shock.¹² Following the literature (i.e., Backus, Kehoe, and Kydland, 1992), we set the standard deviation of the productivity shock to $\sigma_A = 0.008$ and its persistence, to $\rho_A = 0.95$. The standard deviation of the foreign interest rate is set to $\sigma_R = 0.00623$ and its persistence, to $\rho_R = 0.60$ (Rudebusch, 2002, 2006). We then discretize the continuous AR(1) process into a two-state Markov chain, based on Tauchen and Hussey (1991) in the computation of the model.¹³ Thus, in the solution algorithm, there are eight states in the Markov chain, associated with the three exogenous shocks.

4. MODEL SOLUTION

We solve the model by using a global solution method. This allows us to analyze both ‘normal’ business cycles and ‘crises,’ when the small economy is limited by the borrowing constraint. For the competitive equilibrium under strict inflation targeting, and the pegged exchange rate regime, we make use of a policy function iteration approach to solve the model. For the optimal monetary policy solution, we apply the algorithm developed by Schittkowski (2014) to solve the model. More solution details can be found in Devereux and Yu (2014), and Devereux, Young, and Yu (2015).

5. THE EFFECTS OF ALTERNATIVE MONETARY POLICY RULES

5.1 The Steady-State Conditions

It is instructive at this point to describe the workings of the model in simple terms. One immediate property of this set of assumptions is that the domestic agent is on average a borrower, since our calibration implies that in the steady state $\beta R^* < 1$; i.e., households are impatient relative to the rest of the world. As a result, in a steady state, the collateral constraint will bind, since households in the small economy will borrow up to their limit implied by (5). In a steady state, price stickiness is absent. Then, from (10), we can establish that in the steady state the Lagrange multiplier on the collateral constraint is

12. Allowing for correlated shocks would slightly change households’ precautionary saving, but would not alter the main messages in this paper.

13. Adding additional states into the Markov chain alters the quantitative answers, but not the qualitative ones.

given by $\mu = \frac{1 - \beta R^*}{R^*}$. From (7), (11), and (12), we can derive a negative relationship between the steady-state real exchange rate and the steady-state demand for intermediate imports Y_F . A rise in e raises the cost of intermediate inputs, thus reducing Y_F , which also reduces the marginal product of labor. Let us denote this equilibrium relationship $Y_F(e)$. Likewise, it is easy to see that, from the optimality condition for capital (8), we can derive a negative relationship between the capital price q and the real exchange rate, denoted $q(e)$ in the steady state. A higher real exchange rate reduces both employment and intermediate imports, which in turn reduces the marginal product of capital in the steady state, thus reducing q . Putting these parts together gives a steady-state collateral constraint

$$\vartheta(1 + \tau_N)Y_F(e) - b^* = \kappa \frac{q(e)k}{e}. \quad (26)$$

This represents an implicit relationship between external debt $-b^*$ and the real exchange rate. In principle this may be a positive or negative relationship. A real depreciation (rise in e) will reduce Y_F and reduce the need for intra-period borrowing, thus easing the collateral constraint and allowing higher external debt. But a real depreciation will also unambiguously reduce the real value of capital $\frac{q(e)}{e}$ in terms of foreign currency, and tighten the collateral constraint. For our calibration, we find that the latter effect is predominant, so that (26) gives a negative relationship between $-b^*$ and e .

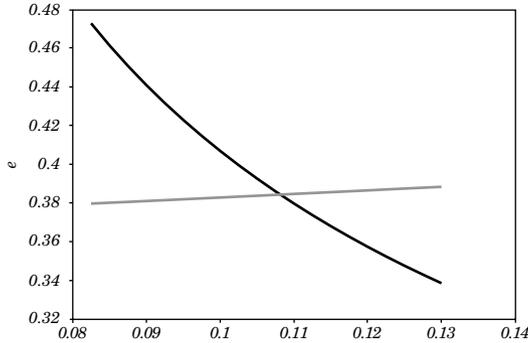
A second link between external debt and the real exchange rate is given by the steady-state balance of payments condition (25)

$$e^{\rho-1}\zeta^* - Y_F(e) = -b^* \frac{R^* - 1}{R^*} \quad (27)$$

A rise in e increases foreign demand for domestic final goods, and reduces the demand for imported inputs. As a result, a higher trade balance increases the steady-state sustainable foreign debt $-b^*$.

Figure 1 illustrates the determination of e and $-b^*$ in the steady state. A permanent easing of the collateral constraint (a rise in κ) will shift up the locus representing (26), thus raising both e and $-b^*$. A higher domestic productivity will shift up both (26) and (27), and for our calibration, will lead to a rise in the steady state e and $-b^*$. Hence, for these two shocks, in the steady state, we find that higher net external debt is associated with a higher (more depreciated) real exchange rate.

Figure 1. Steady State Real Exchange Rate and External Debt



Notes: Debt and Real Exchange Rate determination in the steady state. The black (downward sloping) locus is the steady-state financial constraint. The gray (upward sloping) locus is the steady-state balance of payments condition.

In a stochastic equilibrium, it is no longer necessarily the case that the collateral constraint binds. But, as suggested by the steady-state analysis, we will find that a binding constraint is associated with a higher external debt and a higher real exchange rate.

5.2 Price Stability versus Ramsey Optimal Monetary Policy

The characteristics of the model in a stochastic equilibrium are very different from those in the steady state. In general, the collateral constraint may or may not bind. As shown in Devereux and Yu (2014), for a similar constraint, agents will in general engage in precautionary saving, so that external debt is lower than that implied by the steady state, and the collateral constraint may not bind over a large part of any given sample period. In fact, for our calibration, we find that the degree of precautionary saving is strong enough that the constraint is slack for almost all the time. Nevertheless, as we see below, episodes when the constraint binds display substantially different dynamic properties than when the constraint is slack. We describe episodes with binding constraints as ‘crisis events’.

We begin by outlining the characteristics of the basic sticky price model under flexible exchange rates, and comparing a monetary policy which follows a policy of strict price stability with an optimal (time-consistent) monetary rule derived in the manner described above.

The solution algorithm generates decision rules, or ‘policy functions’, representing mappings from the state of the system to all the endogenous variables at any time period. The model has only one endogenous state variable, the level of net foreign assets b_t^* , and three exogenous states, represented by the shocks (κ_t , α_t and R_t^*). We illustrate the equilibrium policy functions in figure 2. The figure gives the mapping from the level of net foreign debt $-b^*$ to output, the price of capital, the rate of inflation, the interest rate, and the real exchange rate. Since there are eight possible exogenous states of the world in the Markov chain over the three shocks, there is a separate mapping for all eight possible outcomes. For clarity, we show the mapping for the ‘worst state,’ representing the lowest value for κ_t , the lowest productivity state, and the highest state for the foreign interest rate (state 1), and the ‘best state,’ representing the alternative for all three exogenous shocks (state 8).

Figure 2. Equilibrium Policy Functions for the Regime of Price Stability and Ramsey Optimal Policy

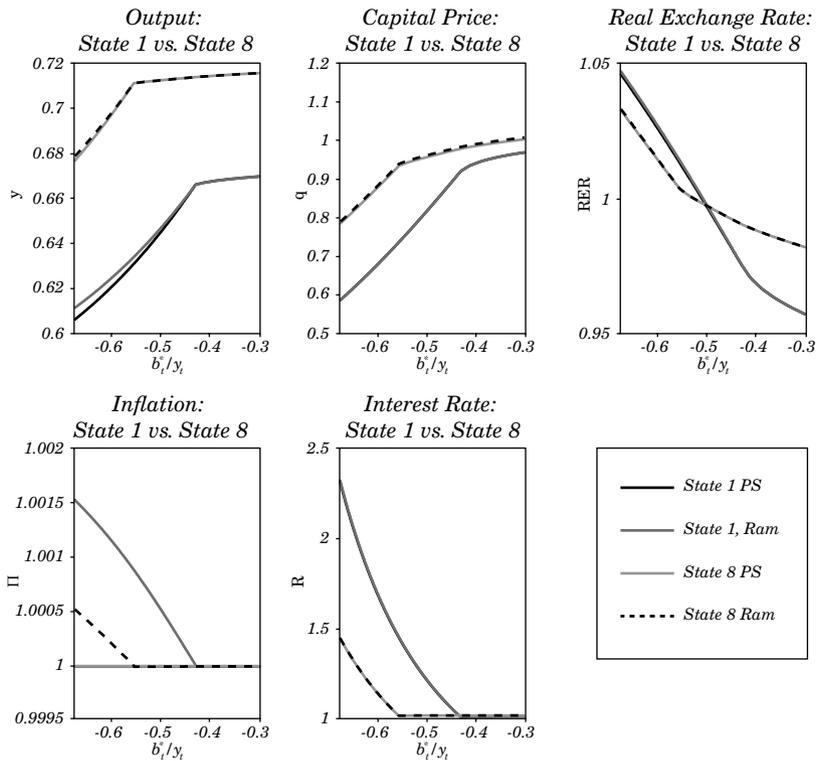


Figure 2 indicates that there is a kink in the policy functions that occurs when the collateral constraint begins to bind at a critical level of net external debt. This occurs at different levels of debt, depending on the state of the exogenous shocks. At low levels of debt, the collateral constraint is slack. Output and capital prices are higher in state 8 than in state 1, and are identical for the policy of price stability and the Ramsey optimal policy. The real exchange rate is higher, given a higher level of output under both monetary policy regimes. Inflation is set equal to zero for the Ramsey policy, while the nominal interest rate is fixed and equal to the world interest rate. As debt rises, but before the collateral constraint binds, the real exchange rate depreciates in both states 1 and 8, the capital price falls, and GDP falls as well. Intuitively, the higher external debt depresses domestic consumption demand, thus leading to a rise in the real exchange rate and reducing the purchase of intermediate imports, which in turn leads to a fall in domestic production and, through a fall in the return on capital, reduces the price of capital itself.

A further rise in net external debt leads the collateral constraint to bind and, thus, the economy enters the crisis zone. This occurs at a debt-to-GDP ratio of in state 1 and in state 8. With the binding constraint, the kink in the policy rules indicates that the price of capital falls more quickly as net external debt rises. This further tightens the collateral constraint, thus raising the external finance premium and leading to a sharp fall in intermediate imports and GDP, with a large real exchange rate depreciation. As the threshold debt level for state 1 is much less than that for state 8, we see a non-monotonicity in the real exchange rate across states. The real exchange rate depreciation in state 1 is large enough that e may be higher in state 1 than state 8 for intermediate levels of debt for which there is a crisis in state 1 but not in state 8.

How does optimal Ramsey monetary rule respond to the crisis? Panel 4 indicates that the policymaker allows inflation to increase as debt hits the threshold and the collateral constraint binds. The rise in inflation allows for a slightly higher real exchange rate and partially cushions the fall in GDP. Obviously, under the price stability rule, inflation is unchanged as the economy moves into a crisis. But panel 5 of figure 2 indicates that the nominal interest rate rises as the collateral constraint binds. Moreover, this occurs approximately equally under both the price stability rule and the optimal monetary rule. Note that the rise in the nominal interest rate is equivalent to a rise in the real rate under price stability. Comparing (9) and (10), we

see that a binding collateral constraint opens up a gap between the domestic and world interest rate, given the path of the real exchange rate. Thus, as the economy enters the crisis zone, the domestic real interest rate rises, and this requires a rise in the policy rate required to maintain price stability. So under either alternative monetary rule, the policy interest rate must rise in a crisis, despite that the economy is operating under a flexible exchange rate.

While the Ramsey optimal policy allows for a rise in inflation in response to the crisis, we see from the policy function for output that this has little consequence for the path of GDP, conditional on external debt and the state of the exogenous shock processes. The rise in inflation allows for a higher level of output and employment through the channel of the New Keynesian Phillips curve (17), thus leading to a higher level of intermediate imports due to a greater real exchange rate appreciation. But this effect is very slight, intuitively because the degree of effective price rigidity is quite small in this model, given the forward-looking inflation dynamics in the economy.

The policy functions indicate that there is a zone of vulnerability in the levels of debt-to-GDP for which a crisis may occur, depending on the outcome of the exogenous shocks to leverage, productivity, and the world interest rate. For debt levels between 43% and 56% of GDP, there will be a crisis with probability 1 in the worst state of the world (state 1), but a crisis may not occur in other states. Given this, it might be expected that an optimal policy would take action to prevent the economy from entering this zone of vulnerability. But a key feature of figure 2 is that it establishes that there is no ‘macroprudential’ element in an optimal monetary policy. Outside of the crisis zone, the Ramsey optimal monetary policy strictly adheres to the price stability rule. It is only when the crisis occurs, conditional on the level of debt and the state of the exogenous shocks, that inflation is allowed to rise. The optimal policy does not involve a rise in policy rates at any levels of debt that occur ‘near to’ the crisis threshold levels.¹⁴

14. This finding is tied to the form of financial friction in the model, and is explained for a wider class of policies in Devereux, Young, and Yu (2015). In Bianchi and Mendoza (2010), a macroprudential role for capital taxes arises from the planner’s desire to influence the current period asset price. Given the nature of the collateral constraint (5) in our model, it is the future period asset price that is the critical determinant of the degree to which the constraint binds. As a result, it is always better for the planner to wait until the collateral constraint binds to depart from a policy of strict inflation targeting.

5.3 Moments

Tables 2 and 3 describe the first and second moments from the model simulations, under the two alternative regimes: strict inflation targeting, and optimal monetary policy (we discuss the pegged exchange rate case below). Each table contains two panels. The first panel reports moments for the whole sample simulation, including both ‘crisis’ and normal times, while the second panel reports moments computed only during a ‘crisis,’ where the collateral constraint binds.

Comparison of sample means shows there is little difference between the optimal monetary rule and the regime of price stability, as suggested by the policy functions described above. Outside of a crisis, the outcomes are essentially identical, since as we have seen, the two monetary rules are identical when the collateral constraint does not bind. In crisis times, output is slightly higher under the optimal monetary rule.

The comparison of standard deviations across the two regimes is similar. In normal times, the standard deviation of output, the real exchange rate and consumption are equal. During crisis episodes, output and consumption volatility is slightly lower under the optimal monetary policy, while real exchange rate and inflation volatility is higher. The optimal policy deviates from the pure price stability objective in crisis times, but the volatility of inflation is still extremely low.

Overall, the moment comparison supports the message from the policy functions discussed above—a Ramsey optimal policy is very close to a pure price stability rule, despite the presence of financial frictions and recurrent financial crises.

5.4 The Pegged Exchange Rate

We now turn to an analysis of the pegged exchange rate regime. Under an exchange rate peg, there is an additional state variable, in the form of the lagged real exchange rate as described in equation (23). Thus, the policy functions must be represented in the form of two dimensional mappings from the state $\{b_t^*, e_{t-1}\}$ to the endogenous variables, for each exogenous state of the world. Figures 3 and 4 illustrate the policy functions for states 1 and 8, where the states are as described above. The figures show the mapping from the endogenous states $\{b_t^*, e_{t-1}\}$ to output, the price of capital, the real exchange rate and inflation, the interest rate, and in addition, for clarity, we show

the value of the Lagrange multiplier μ , which makes it easier to identify the points in the state space where the collateral constraint begins to bind.

The characteristics of the policy functions under the peg are mainly similar to those in the flexible exchange rate. As debt increases, output falls, the capital price falls, and there is a real exchange rate depreciation. But there are two key differences. The first one is that the policy rules depend on the predetermined real exchange rate e_{t-1} . In the case of the output function, for instance, a higher value of e_{t-1} leads to a higher level of output, for any given value of debt. From (23), we see that for a given e_t , a higher lagged real exchange rate implies a higher level of inflation, *ceteris paribus*. Panel 4 of figure 3 illustrates the positive relationship between e_{t-1} and inflation, conditional on $-b_t^*$.

Figure 3. Equilibrium Policy Functions for the Pegged Exchange Rate Regime in State 1

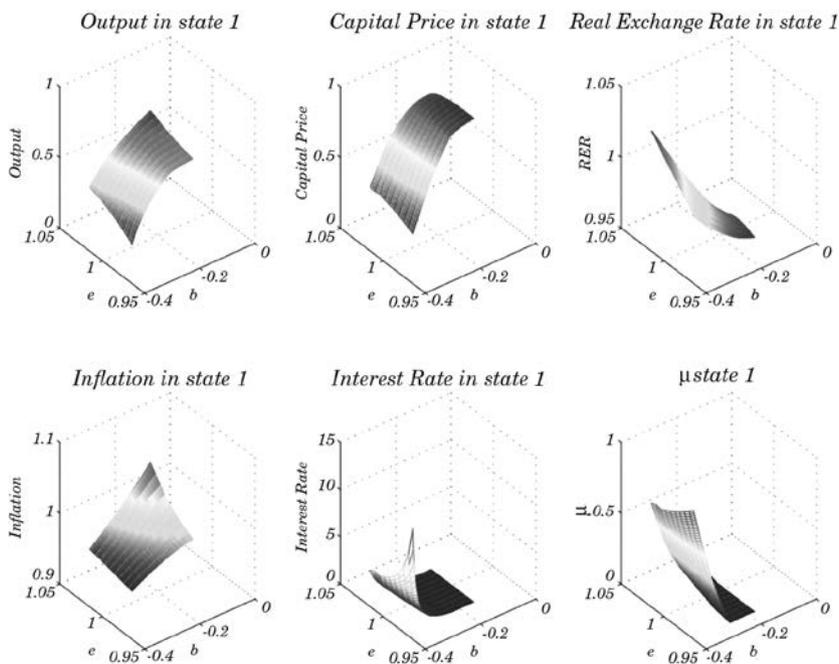
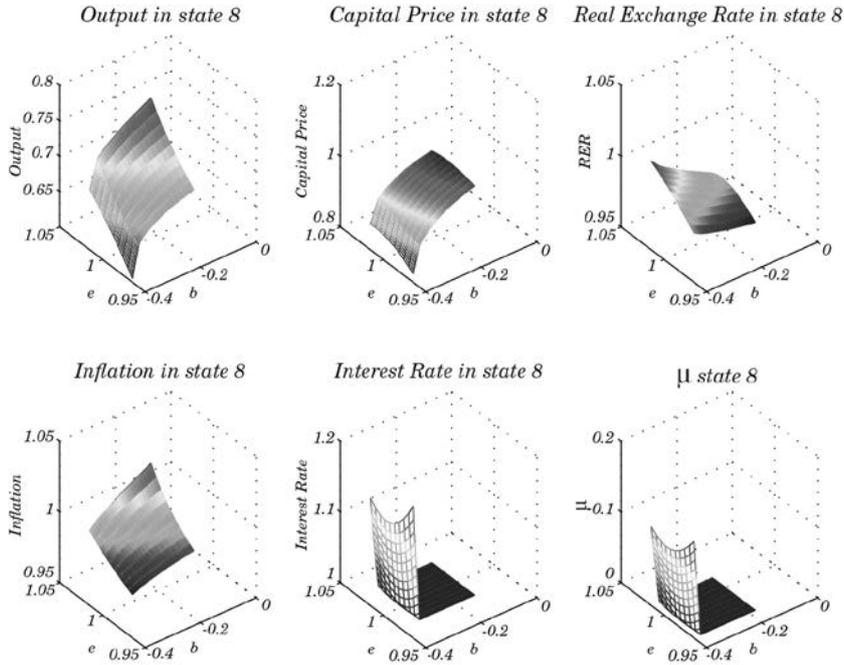


Figure 4. Equilibrium Policy Functions for the Pegged Exchange Rate Regime in State 8



More importantly, however, we see from panel 4 that the process for inflation under the pegged exchange rate is critically different from that of the optimal floating exchange rate rule. In general, inflation is non-zero, even away from crisis states. For low levels of debt, inflation tends to be positive, particularly for high lagged values of e_{t-1} , as discussed in the preceding paragraph. But when the collateral constraint begins to bind, the inflation stance is reversed, and the pegged exchange rate rule leads to a deflation, as the policymaker must generate a real exchange rate depreciation through falling prices. Thus, the behavior of domestic inflation in a crisis under a pegged exchange rate is exactly the opposite of that in the optimal floating exchange rate regime.

Figure 5 projects the policy functions for the pegged exchange rate regime by restricting the functions to be defined over the mean of the exchange rate states, so as to be more easily comparable with the one-dimensional policy functions for the floating exchange rate regime.

The figure compares the outcomes for the exogenous state 1 described earlier, and contrasts the policy mappings under the optimal monetary policy with those from the pegged exchange rate. Outside of the crisis state, output is slightly higher under the pegged exchange rate, but output falls by much more when the collateral constraint binds. It is clear that the major contrast with the floating regime is the behavior of the inflation rate. Under the floating exchange rate with optimal monetary policy, inflation is zero outside of the crisis zone, and rises in the crisis. Under the peg, inflation is positive outside of the crisis, and falls below zero in the crisis zone. During a crisis, in order to facilitate a real exchange rate depreciation in the absence of nominal exchange rate flexibility, the policymaker needs to generate deflation.

Figure 5. Policy Function Projection for the Pegged Exchange Rate, Compared to the Ramsey Optimal Policy Function

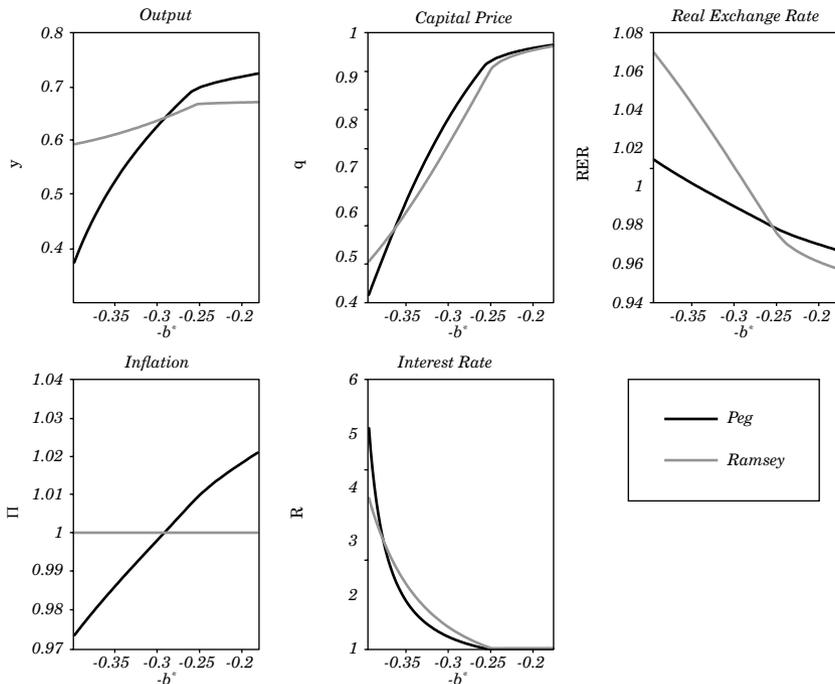
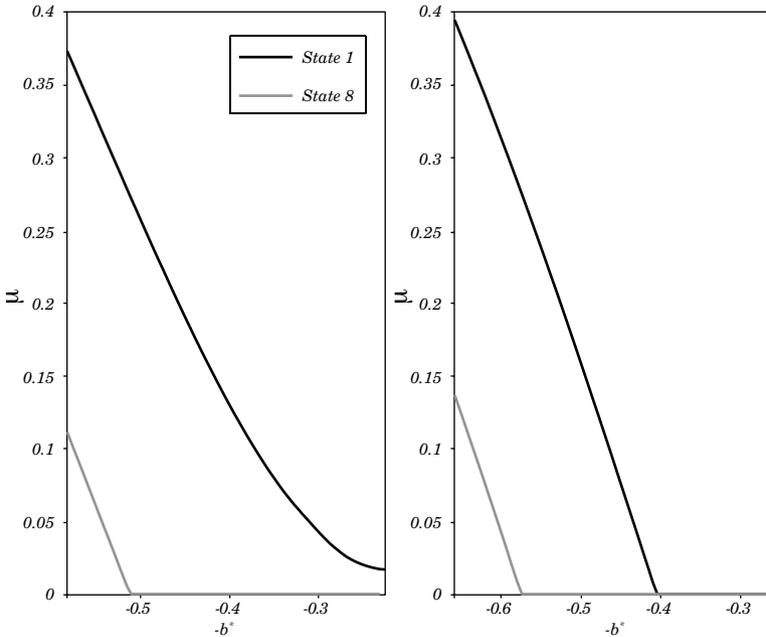


Figure 6 plots the range of values for debt-to-GDP for which the country is in the zone of vulnerability to crises. As before, the figure illustrates the lowest value of debt-to-GDP for which the crisis will occur (which happens if state 1 occurs) and the highest value of debt-to-GDP for which the crisis will occur (which happens when state 8 occurs). But now, the zone of vulnerability depends critically on the predetermined real exchange rate e_{t-1} . The left hand panel shows the range of debt-to-GDP values which will precipitate a crisis for the highest value of e_{t-1} (i.e., most depreciated real exchange rate), while the right hand panel illustrates the equivalent range for the lowest (most appreciated) value of e_{t-1} . For high real exchange rates, the crisis is much more likely. The range of debt-to-GDP ratios goes from 0.2 to 0.5. With the lowest value of e_{t-1} , the range of crisis vulnerability is much smaller.

Figure 6. Debt Zone of Crisis Vulnerability for High and Low Real Exchange Rate States in the Pegged Exchange Rate Regime



Hence, we see that, while the risk of crises under a flexible exchange rate may be summarized by the level of debt-to-GDP (as well as the exogenous states of the world), under the pegged exchange rate, crisis risk depends both on the real exchange rate and the debt-to-GDP ratio. Moreover, the model implies that a pegged exchange rate may impose more severe limits on the range of permissible debt levels necessary to avoid a crisis. For a high real exchange rate, crises may occur for much lower levels of debt than in a flexible exchange rate regime.

Tables 2 and 3 compare the pegged exchange rate regime to the floating regimes in terms of the simulated mean and volatility. Over the whole sample, there is little difference between the inflation-targeting regime (or optimal monetary policy) and the pegged regime. In terms of means, output is effectively identical across these regimes. Net external debt is slightly lower under the peg. This occurs due to the greater degree of precautionary saving undertaken by households in a pegged exchange regime. Precautionary saving is higher because consumption volatility is substantially higher in crisis outcomes under a pegged regime (as we see below).

The domestic interest rate and the external finance premium are identical across the three regimes. When we look at volatilities during normal times, there is more of a contrast between the peg and the inflation-targeting regime. The real exchange rate is significantly more volatile in the latter case, as the nominal rate is free to move, while under the peg, the real exchange rate can move only through costly domestic price adjustment. Output volatility is in fact lower under a peg.¹⁵ However, consumption volatility is higher, due to the absence of the exchange rate as a stabilizing mechanism.

When the country enters a crisis, the impact is much greater in the pegged regime. The reversal in the current account is more extreme, since in the absence of rapid real exchange rate adjustment, domestic interest rates rise much more under the peg, thus leading to a substantially greater fall in domestic absorption. The mean level of external debt during a crisis is 10% lower in a fixed exchange rate environment than under either alternative floating regime. Interest rates in floating and fixed exchange rate regimes are identical outside of crises, but they diverge sharply when the country is borrowing-

15. This is due to the presence of productivity shocks, as when the exchange rate is fixed and prices are sticky, productivity shocks have less of a short-run impact on domestic production. See Devereux and Yu, 2016 for a further explanation.

constrained. In a crisis, the average domestic interest rate rises to 10% under the floating regimes, but it rises to 17% under the peg. Note that domestic and foreign interest rate differentials during a crisis are driven by a combination of anticipated exchange rate movements (as implied by uncovered interest rate parity) and the presence of the external finance premium, since it becomes much more expensive to borrow abroad when the country is collateral-constrained. The interest rate differential under the peg fully reflects the much greater external finance premium, as shown in table 2.

The lack of nominal exchange rate variation leads to much greater volatility of consumption and output under the peg than under either flexible exchange rate regime, when volatility is measured over episodes of a binding collateral constraint. In crisis times, the standard deviation of output under the peg is well over twice that in the floating regimes. The standard deviation of consumption is twice that in the floating regime. This accounts for the increased precautionary saving associated with the peg.

The tables also indicate that under the price stability regime, the crisis frequency is 11%. The Ramsey optimal policy does slightly reduce the crisis frequency to 10.7%. Surprisingly, under the pegged exchange rate, the crisis frequency is significantly lower, at 6.8%. Partly this is due to the lower average debt-to-GDP ratio in the peg, given the higher precautionary saving. But the composition of shocks also matters. This result is further explored in Devereux and Yu (2016). There, it is shown that the lower frequency of crises under a peg is tied to the presence of domestic productivity shocks. Under an exchange rate peg, the price of capital is less volatile in the face of productivity shocks and, hence, crisis frequency may be lower. Despite this, conditional welfare is lower under an exchange rate peg, as shown in table 2.¹⁶

The model therefore implies that the impact of ‘sudden stop’ financial crises in emerging markets is critically dependent upon the monetary policy stance being followed by each country. Whatever the monetary policy in place, when countries are hit by binding borrowing constraints, crises are associated with sharp downturns and a process of deleveraging. But the depth of the downturn is crucially linked to the exchange rate regime. If the policymaker maintains a pegged exchange rate when a crisis hits, it has a much more damaging effect.

16. Interestingly, Domac and Martinez-Peria (2003) show that adopting a fixed exchange rate regime can reduce the likelihood of banking crises for developing countries during 1980-1997.

Table 2. Model Moments: Price Stability, Ramsey Optimum, Pegged Exchange Rate

	<i>Mean</i>		
	<i>Price Stability</i>	<i>Ramsey</i>	<i>Peg</i>
<i>Probability of crisis</i>	11.1	10.6	6.8
<i>Conditional welfare</i>	0.3898288	0.388289	0.3893
<i>Panel A: the whole sample</i>			
<i>Output</i>	0.6877	0.6877	.6877
<i>Debt-GDP</i>	0.3185	0.3183	0.3163
<i>Capital Price</i>	0.9364	0.9364	0.9338
<i>Domestic Interest Rate</i>	1.025	1.025	1.025
<i>External Finance Premium</i>	$0.74.e^{-2}$	$0.74.e^{-2}$	$0.73.e^{-2}$
<i>Panel B: the subsample with binding constraints</i>			
<i>Output</i>	0.6645	0.6652	0.6492
<i>Debt-GDP</i>	0.461	0.458	0.427
<i>Capital Price</i>	0.8738	0.8734	0.860
<i>Domestic Interest Rate</i>	1.11	1.11	1.17
<i>External Finance Premium</i>	$0.67.e^{-1}$	$0.64.e^{-1}$	$1.07.e^{-1}$

Notes: The moments are generated by a simulation of 210,000 periods with dropping the first 10,000 periods. A crisis scenario is defined as a binding collateral constraint.

Table 3. Model Moments: Price Stability, Ramsey Optimum, Pegged Exchange Rate

	<i>Standard Deviation</i>		
	<i>Price Stability</i>	<i>Ramsey</i>	<i>Peg</i>
<i>Panel A: the whole sample</i>			
<i>Output</i>	1.8	1.79	1.65
<i>Consumption</i>	1.59	1.57	1.71
<i>Real Exchange Rate</i>	0.69	0.7	0.3
<i>Inflation</i>	0	0.01	0.3
<i>Capital Price</i>	3.43	3.42	3.05
<i>Panel B: the subsample with binding constraints</i>			
<i>Output</i>	1.82	1.79	4.49
<i>Consumption</i>	2.53	2.51	4.9
<i>Real Exchange Rate</i>	1.14	1.18	0.52
<i>Inflation</i>	0	0.03	0.6
<i>Capital Price</i>	5.7	5.79	7.72

Notes: The moments are generated by a simulation of 210,000 periods with dropping the first 10,000 periods. A crisis scenario is defined as a binding collateral constraint.

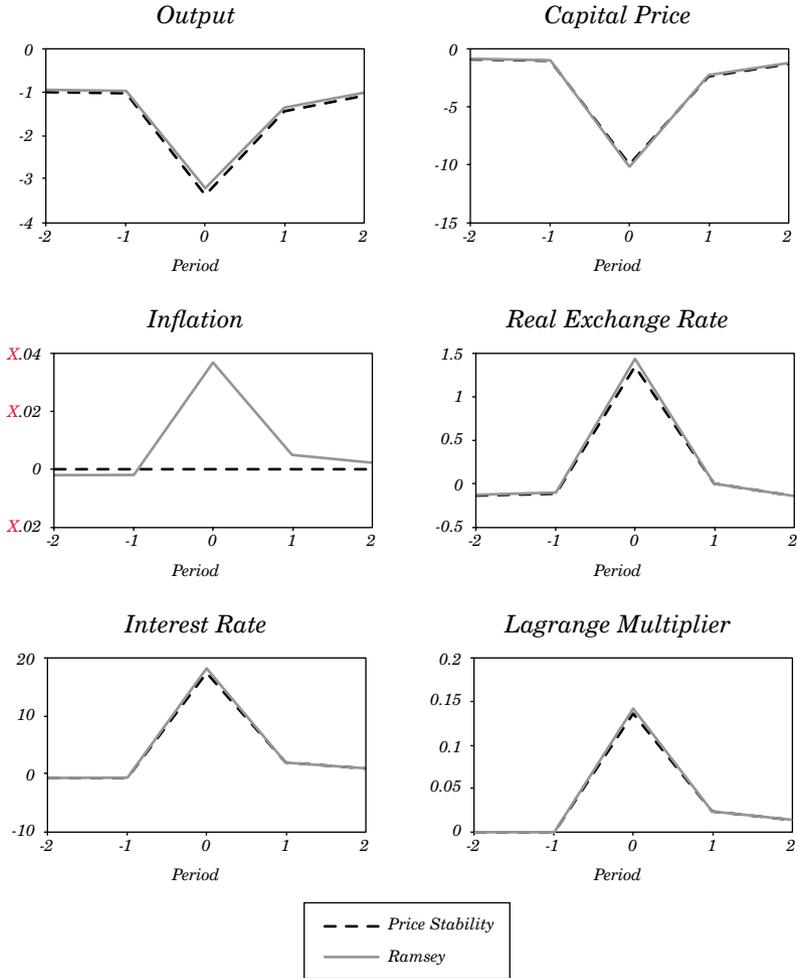
5.5 Crisis Events

To see more clearly what happens in a typical financial crisis, we illustrate the model simulations in terms of an event analysis. We define an ‘event’ in the simulations as a situation where the collateral constraint is non-binding for two periods, and then becomes binding for at least one period following this. Then we average the responses of all macroeconomic variables across all such events.

Figure 7 reports the response of output, the price of capital, the real exchange rate, inflation and interest rates, and the Lagrange multiplier (which gives a measure of the response of the External Finance Premium) for the comparison of the two flexible exchange rate regimes (price stability *versus* Ramsey optimal monetary policy). As suggested by the policy functions and the moment analysis above, there is only a slight difference in the crisis experience between the two monetary policy regimes. Inflation rises in a crisis under the Ramsey policy, thus leading to a greater real exchange rate depreciation and a slightly smaller reduction in output.

Figure 8 compares the crisis response under a peg to that of the two floating exchange rate regimes. Clearly, the response under a peg is substantially greater in most dimensions. The multiplier jumps much more under the peg, which indicates a much greater rise in the external finance premium. This is reflected in a larger increase in the domestic interest rate. The interest rate rises to 18% in the floating regimes, but to almost twice as much in the peg. Thus, the crisis is associated with a large temporary deviation from interest parity. We can equivalently think of this as the necessary interest rate defence required to maintain a peg in face of a capital market crisis.

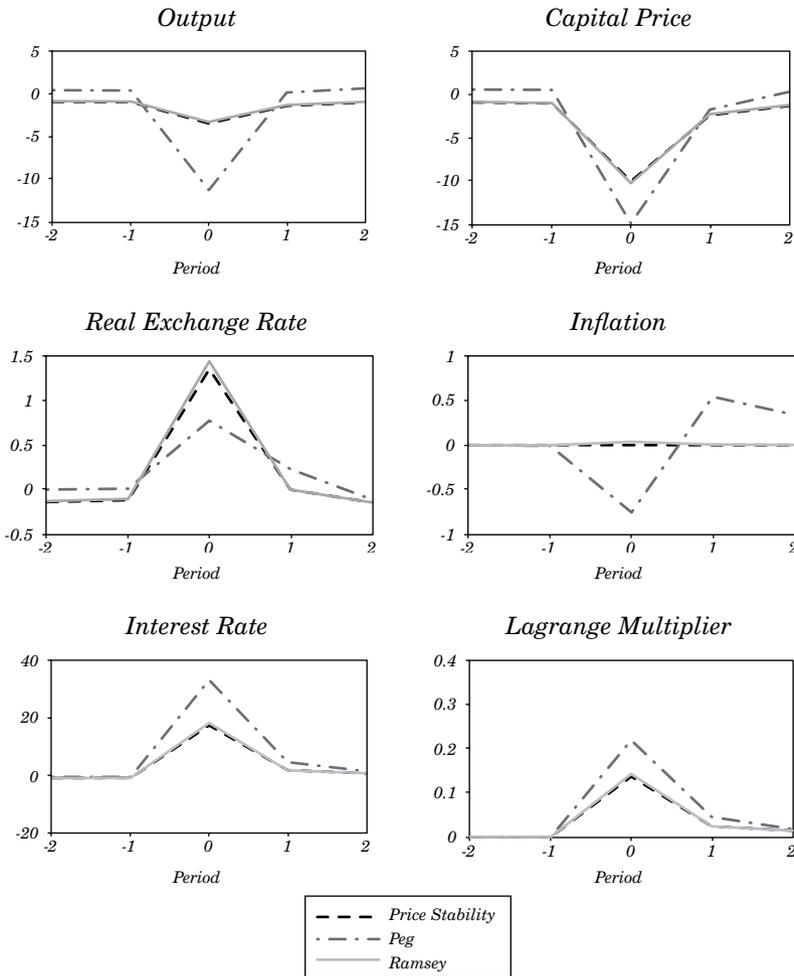
Figure 7. Crisis Events for the Price Stability Regime and the Ramsey Optimal Policy



While the real exchange rate depreciates in both regimes, there is a much larger depreciation under the floating exchange rate regime. Because of the inverse relationship between inflation and real exchange rate, under the pegged exchange rate, the real exchange rate depreciation requires a substantial deflation on impact and then a dramatic inflation following the impact period. The large deflation

required to maintain the peg has significant consequences for the real economy. Output falls by 10% under the peg compared with approximately 3% in the floating regime. The rapid deflation and the spike in the domestic interest rate lead to a much larger fall in the price of capital under the peg, thus further increasing the external finance premium through the ‘financial accelerator’ process.

Figure 8. Crisis Events for the Price Stability Regime, the Ramsey Optimal Policy, and the Pegged Exchange Rate Regime



Finally, the figures also establish that, while an optimal monetary policy differs from the strict inflation-targeting regime during a crisis, in practice, there is little difference between the two policies, even in a crisis. In contrast to the strict inflation-targeting regime, we see that there is a jump in inflation during a crisis under an optimal monetary policy. But this is much smaller than the (negative) response of inflation in the peg and has little effect on the overall response of the real economy, as compared to that under the strict inflation-targeting regime. Also, as discussed above, the event figure for inflation under optimal monetary policy in the floating regime shows that monetary policy only reacts to disturbances in crisis and doesn't serve as a macroprudential policy.

6. CONCLUSION

This paper explores the ways in which a small, emerging market country that suffers from financial vulnerabilities can utilize monetary and exchange rate policy to avoid macro spillovers from external shocks. The paper combines the literature on sudden stops in financial markets with the New Keynesian literature on nominal wage and price rigidities. We find that, while the benefit of monetary policy in dealing with financial crises depends on the degree of nominal rigidity, the effect of crises under pegged exchange rates may be very costly. Thus, even in the presence of large spillover effects from the rest of the world's financial fragilities which generate recurrent crises, there remains an important policy 'trilemma' for emerging market economies that are committed to capital market openness.

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APPENDIX A. MEASURES OF WELFARE

The lifetime utility for a representative household in the small economy, conditional on the initial debt level and exogenous shocks can be written as

$$Wel(b_0^*, Z_0) \equiv E_0 \left\{ \sum_{t=0}^{\infty} \beta^t U(\tilde{C}_t) \right\} = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \frac{\tilde{C}_t^{1-\sigma} - 1}{1-\sigma} \right\}. \tag{A-1}$$

We define a certainty equivalence of effective consumption $\tilde{C}(b_0^*, Z_0)$ in a policy regime conditional on an initial state (b_0^*, Z_0) as

$$Wel(b_0^*, Z_0) = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \frac{\tilde{C}(b_0^*, Z_0)^{1-\sigma} - 1}{1-\sigma} \right\} = \frac{\tilde{C}(b_0^*, Z_0)^{1-\sigma} - 1}{1-\sigma} \frac{1}{1-\beta}.$$

Rearranging the equation yields

$$\tilde{C}(b_0^*, Z_0) = \left[Wel(b_0^*, Z_0)(1-\sigma)(1-\beta) + 1 \right]^{\frac{1}{1-\sigma}}. \tag{A-2}$$

We will use $\tilde{C}(b_0^*, Z_0)$ to measure conditional welfare in the main text.

The unconditional welfare Wel is measured in a similar way except that the welfare Wel is a weighted average of conditional welfare $Wel(b_t^*, z_t)$ over the whole domain in the stationary equilibrium.