# Monetary Policy Responses to External Spillovers in Emerging Market Economies*


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**Abstract**

While many emerging economies have liberalized financial markets and floated their currencies, they remain highly vulnerable to real and financial shocks from the US and other advanced economies. This paper explores the degree to which an emerging market economy can utilize monetary and exchange rate policies to respond to external and internal macroeconomic shocks when the country is prone to endogenous financial crises. Financial fragilities are modelled as occasionally binding borrowing constraints. Financial constraints may interact with price and wage rigidities in a way that offers a dual role for monetary policy. The central contribution of the paper is to combine the analysis of 'sudden stops' in capital markets with traditional New Keynesian analysis of monetary and exchange rate policy.



**Keywords:** Sudden stops, Pecuniary externality, Monetary policy, Exchange rate regimes, Capital controls

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# 1 Introduction

Despite the remarkable progress made in many emerging and middle income economies over the last few decades, and the continuing liberalization in financial markets and integration into the global financial system, these countries remain highly vulnerable to real and financial shocks coming from the US 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 some degree of reversal in the process of financial openness is required in order to manage their economies. 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 to be employ controls on international capital inflows.

Our paper is motivated by this recent debate. We explore a series of theoretical approaches to modeling financial crises in emerging market economies, and combine these 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 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, attempting 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, models financial crises as occurences 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 (see, e.g. Gali and Monacelli (2005)). The synergies involved in blending these two frameworks allows us to provide a comprehensive evaluation of the role of

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

monetary policy in the incidence of and response to emerging market financial crises.

Our analysis is in two main parts. In the first part, 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 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, requiring 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. By contrast, we find that there is little difference between a policy of strict inflation targeting and an optimal discretionary monetary policy. 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 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 occurence of a crisis.

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.

We then extend the analysis to a model where there are multiple sources of nominal rigidity - namely both wage and price rigidity. In this model, we find that the benefits of accommodative monetary policy in a crisis may be substantial. Moreover, even outside of crises, an inflation targeting rule is not optimal. But it remains the case that the operation of monetary policy cannot be described as macro-prudential. While an optimal policy is active outside a crisis event, it is not operated in a way to lean against the wind.

## 1.1 Related literature

This work is related to several strands of recent literature, which we break up into the following categories.

### 1.1.1 Macroprudential capital controls

Since the onset of the global financial crisis, there have been a surge of interest in capital flow regulations. Bianchi (2011) studies an endowment economy with tradable and nontradable sectors. Private agents don't internalize the effects of their borrowing on asset prices in a crisis, which leads to an overborrowing ex-ante. 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 nontradable sectors, private agents may engage in underborrowing , as show in Benigno, Chen, Otrok, Rebucci and Young, 2013.

Schmitt-Grohe and Uribe (2016) 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) explores 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. The present paper explores the role of capital flow taxes or subsidies across different exchange rate regimes.

### 1.1.2 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 favour of floating exchange rates. Based on the experience of the Eurozone, Schmitt-Grohe and Uribe (2013) 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 (2013b) extends Bianchi's model (Bianchi, 2011) to a Gali-Monacelli type of small open economies (Gali and Monacelli, 2005) and shows that debt deleveraging may generate a world-wide recession in a monetary union. In a similar vein, Fornaro (2013a) investigates the tradeoff between price and financial stability in a small open economy with sticky wages and credit constraints. Building upon Schmitt-Grohe and Uribe (2013), Ottonello (2015) studies exchange rate policy and capital controls in a small open economy. Policy makers 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 deviate from the target dramatically 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.

#### 1.1.3 Currency manipulation and currency wars

It has long been recognized that even in a small economy, monetary authorities can manipulate their currency in favour 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 the 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 assumptions, while section **??** shows a model extension to sticky wages. Section 5 briefly explains the solution method. Section 6 presents the main results, while 7 presents the results of the extension of the model to sticky wages. Section 8 presents some brief conclusions.

## 2 The model

All the analysis in the paper will be based on a prototype model of a a small open economy. The baseline model structure is mostly taken from Devereux, Young and Yu (2015), which itself 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 [2] 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, $Y_{F,t}$ imported intermediate inputs, $L_t$ labor demand and $K_t$ 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. Assume that the foreign demand function for the domestic consumption composite, $X_t$, can be written as

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

where $P_t$ is the price of the domestic composite good, and $\mathcal{E}_t$ is the nominal exchange rate (price of foreign currency). The term $\zeta_t^*$ 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 so can be ignored as a component of the foreign CPI. Hence, we

[2] In a later section, we will allow for sticky wages, which requires the assumption that households have some monopolistic power in labor supply.

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 [3]

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

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

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

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, $\vartheta$ 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. [4] The parameter $\kappa_t$ capture 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.

Households own domestic firms equally. Each household makes identical decisions in a symmetric

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

[4] 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 so to 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 policy maker to conflate the policy problem associated with nominal rigidities and the collateral constraint with the exploitation of market power in the economy's terms of trade.

equilibrium. The representative firm-household faces the following budget constraint

$$P_t c_t + Q_t k_{t+1} + \frac{B_{t+1}}{R_{t+1}} + \frac{(1-\tau_{c,t})B^*_{t+1}\mathcal{E}_t}{R^*_{t+1}} \leq W_t l_t + k_t(R_{K,t} + Q_t) + B_t + B^*_t\mathcal{E}_t + T_t$$
$$+ \left[P_{M,t}M(Y_{F,t}, L_t, K_t) - (1+\tau_{N,t})Y_{F,t}\mathcal{E}_t - W_t L_t - R_{K,t}K_t\right] + D_t. \tag{6}$$

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 $B^*_{t+1}\mathcal{E}_t/R^*_{t+1}$. The variable $\tau_{c,t}$ denotes a capital tax imposed by domestic authorities. A higher value of $\tau_{c,t}$ raises the cost of borrowing in foreign currency, for a given gross interest rate $R^*_{t+1}$. In sections 6 and 7 below we will set this tax to zero, but in a later section we explore the consequences of allowing for an optimal tax. The right-hand side of (6) consists of labor income $W_t l_t$, the gross return on capital $k_t(R_{K,t}+Q_t)$, the gross return on domestic currency bond holdings $B_t$ and foreign bond holdings $B^*_t\mathcal{E}_t$, lump-sum transfers from government $T_t$, profits from wholesale good producers $P_{M,t}M_t - (1+\tau_{N,t})Y_{F,t}\mathcal{E}_t - W_t L_t - R_{K,t}K_t$ and profits from the rest of 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 $e_t = \mathcal{E}_t P^*_t/P_t$. Higher $e_t$ implies a real exchange rate depreciation.

We may summarize the household's optimality decisions in the following way. The optimal labor supply decision satisfies

$$w_t = \chi l_t^{\nu}. \tag{7}$$

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

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

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 households 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

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

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

$$1 - \tau_{c,t} = \mu_t R^*_{t+1} + E_t \left\{ \beta \frac{U_c(t+1)}{U_c(t)} \frac{e_{t+1}}{e_t} R^*_{t+1} \right\} \tag{10}$$

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 that 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) imply 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 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

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

$$p_{M,t} \frac{\alpha_L M_t}{L_t} = w_t \tag{12}$$

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

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

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

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 one. Each producer differentiates wholesale goods into a variety of final goods, where each variety is an imperfect substitute for the other varieties, 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 $Y_t(i)$

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

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

$$Y_t(i) = M_t(i). \tag{16}$$

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

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

Here $\tau_H$ 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 $\pi$ is the inflation target. In the cost function $\phi(\cdot)$, $\phi_P$ characterizes the basic Rotemberg price adjustment cost and $\gamma$ 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 $Y_t(i) = Y_t$ in equilibrium. The optimality condition for price-setting can be simplified as

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

Real profits from intermediate producers are

$$\begin{aligned} d_{H,t} \equiv \frac{D_{H,t}}{P_t} &= (1+\tau_H) Y_t - p_{M,t} Y_t - \phi(\pi_t) Y_t \\ &= Y_t \left[ (1+\tau_H) - p_{M,t} - \phi(\pi_t) \right]. \end{aligned} \tag{18}$$

with

$$\phi(\pi_t) = \phi_P \frac{\exp\left(\gamma\left(\pi_t - \pi\right)\right) - \gamma\left(\pi_t - \pi\right) - 1}{\gamma^2}$$

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, including the labor market and consumption $l_t = L_t$, $c_t = C_t$. 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

$$\int_0^1 Y_t(i) di = \int_0^1 M_t(i) di = M_t. \tag{19}$$

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

$$Y_t\left[1-\phi(\pi_t)\right]=C_t+X_t. \tag{20}$$

## 2.3 Government policy

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

$$T_t=-\tau_H Y_t P_t-\frac{\tau_{c,t} b^*_{t+1} e_t}{R^*_{t+1}} P_t+\tau_{N,t} Y_{F,t} e_t P_t. \tag{21}$$

As noted above, we assume also that the government sets a production subsidy $\tau_H$ to offset the monopoly power of price setting. The central bank conducts monetary policy under either a fixed exchange rate or flexible exchange rate regime. In the regime of flexible exchange rates, monetary policy either takes the form of 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 by [5]

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

A variable without a superscript denotes the value at the deterministic steady state. The response coefficients $\alpha_\pi>0$ and $\alpha_Y>0$ 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

$$\pi_t=\frac{e_{t-1}}{e_t}\pi^*_t=\frac{e_{t-1}}{e_t}. \tag{23}$$

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 assume implicitly 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

[5] Note that the change in the nominal exchange rate is a function of the change in the real exchange rates and inflation, $\mathcal{E}_t/\mathcal{E}_{t-1}=\pi_t e_t/e_{t-1}$. Therefore, stabilizing nominal exchange rates and inflation is equivalent to stabilizing both inflation and the real exchange rate.

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.

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.[6]

## 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

$$C_t + \left(\frac{b^*_{t+1}}{R^*_{t+1}} - b^*_t\right) e_t = Y_t \left(1 - \phi(\pi_t)\right) - e_t Y_{F,t}. \tag{24}$$

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

$$X_t - e_t Y_{F,t} = \left(\frac{b^*_{t+1}}{R^*_{t+1}} - b^*_t\right) e_t. \tag{25}$$

## 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 $t = \cdots, 0, 1, 2, \cdots$, given production subsidy $\tau_H$, 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.

[6] 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 (?; ?), 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 $\kappa_t$ 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 US nonfinancial corporations (?) and the corporate leverages in Asian emerging economies (?).[7] 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 40 quarters and the unconditional probability of a low leverage regime is 10% (Bianchi and Mendoza, 2013), implying that a typical leverage crisis will happen every ten years.

Parameters in the production function are set to match imports share (15% of GDP, see ?), labor share (65% of GDP, see Mendoza, 2010) and the external debt-GDP ratio (40%) in emerging economies before the Global Financial Crisis.[8] Given the leverage specification above and relevant ratios, we set $\alpha_F = 0.13$, $\alpha_L = 0.57$ and $\alpha_K = 0.03$. Parameter $\vartheta$ is set to 1.3, implying a share of working capital 20% of GDP (Mendoza, 2010).[9] The equilibrium labor supply in normal times (without credit constraints) is normalized to be one, 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 $\gamma = -100$.[10] Following the new Keynesian literature (?; ?), we set the elasticity of varieties in both domestic and foreign consumption baskets as $\theta = \rho = 10$, implying a price markup of 11%.

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

[8] 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 Gross National Income. Data source: World Development Indicators with indicator code: DT.DOD.DECT.GN.ZS.

[9] Note that $\vartheta$ 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 ?.

[10] The Rotemberg price adjustment cost relates the Calvo price stickiness via $\phi_P = \alpha(\theta - 1)/((1 - \alpha)(1 - \alpha\beta))$ in an economy without collateral constraints (?). $1 - \alpha$ measures the probability of Calvo style price adjustment in each period. Empricial evidence shows that prices rise faster than fall (?) and small price increases occur more frequently than small price decreases for price changes (?).

Table 1: Parameter values

| Parameter | | Values |
|---|---|---|
| *Preference* | | |
| $\beta$ | Subjective discount factor | 0.975 |
| $\sigma$ | Relative risk aversion | 2 |
| $\nu$ | Inverse of Frisch labor supply elasticity | 1 |
| $\chi$ | Parameter in labor supply | 0.4 |
| | | |
| *Production* | | |
| $\alpha_F$ | Intermediate input share in production | 0.13 |
| $\alpha_L$ | Labor share in production | 0.57 |
| $\alpha_K$ | Capital share in production | 0.03 |
| $\vartheta$ | Share of working capital | 1.3 |
| $\phi_P$ | Price adjustment cost | 76 |
| $\gamma$ | Asymmetry of price adjustment cost | -100 |
| $\theta$ | Elasticity of substitution among imported varieties | 10 |
| $\rho$ | Elasticity of substitution in the foreign countries | 10 |
| | | |
| $\zeta$ | Steady state of foreign demand shock | 0.101 |
| $R^*$ | Steady state of world interest rate | 1.015 |
| $A$ | Steady state of TFP shock | 1 |
| | | |
| $\rho_A$ | Persistence of TFP shocks | 0.95 |
| $\sigma_A$ | Standard deviation of TFP shocks | 0.008 |
| $\rho_R$ | Persistence of foreign interest rate shocks | 0.6 |
| $\sigma_R$ | 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 |
| | | |
| *Policy variables* | | |
| $\alpha_\pi$, $\alpha_Y$, $\alpha_e$ | Coefficients in the Taylor rule | |
| $\tau_H$ | Subsidy to final goods producers | $\frac{1}{\theta-1}$ |
| $\tau_{N,t}$ | Gross subsidy to exports | $\frac{1}{\rho-1}$ |

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

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

$$\ln(R^*_{t+1}) = (1-\rho_R)\ln(R^*) + \rho_R \ln(R^*_t) + \epsilon_{R,t+1}$$

where mean productivity is normalized to be one $A = 1$ and the world quarterly real interest rate $R^* = 1.015$ (Mendoza, 2010). We assume that the local productivity shock is uncorrelated with the global liquidity shock.[11] Following the literature (i.e., **?**), 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 persisence $\rho_R = 0.60$ (**??**). 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.[12] Thus, in the solution algorithm, there are 8 states in the Markov chain, associated with the three exogenous shocks.

# 4 Extension to a model with sticky prices and sticky wages

A robust results in many New Keynesian macro models is that price stability is either exactly or approximately an optimal policy. We will find a similar result in some of the analysis below. But it is well known in the macroeconomics literature that with more extensive nominal rigidities, price stability is no longer a fully optimal policy (Erceg et al. 2001). Given this, we will extend the model to incorporate both price and wage stickiness. [13]

We describe here only the model equations that change. Households are now assumed to be endowed with a specific type of labor, $l_t(j)$, for which they are the monopoly supplier to the market. These labor services are aggregated into a labor composite

$$L_t = \left( \int_0^1 l_t(j)^{\frac{\theta_W - 1}{\theta_W}} dj \right)^{\frac{\theta_W}{\theta_W - 1}},$$

where $\theta_W > 1$ is the elasticity of substitution between different types of labor. The wage rate for

[11] Allowing for correlated shocks would slightly change households' precautionary savings but would not alter the main messages in this paper.

[12] Adding additional states into the Markov chain alters the quantitative answers but not the qualitative ones.

[13] A number of papers have documented the role of rigid wages, in particular downwardly rigid wages, for emerging economies during financial crises (for instance, **?**, Schmitt-Grohe and Uribe, 2013).

one unit of aggregate labor services is

$$W_t = \left( \int_0^1 W_t\left(j\right)^{1-\theta_W} dj \right)^{\frac{1}{1-\theta_W}},$$

and the demand for labor of type $j$ is

$$l_t\left(j\right) = \left( \frac{W_t\left(j\right)}{W_t} \right)^{-\theta_W} L_t.$$

To maintain a tractable modelling framework, we permit trade in a full set of contingent securities to eliminate differences across labor types.

Labor income for a household with type $j$ labor now has a new term. In the budget constraint labor income is reduced by a fraction $\psi_t\left(j\right)$, which will reflect resources lost in the adjustment of individual nominal wages. Following Varian (1975) and **?**, we permit asymmetric adjustment:

$$\psi_t\left(\Omega_t^{ind}\right) = \frac{\phi_W}{\gamma_W^2}\left[\exp\left(\gamma_W\left(\Omega_t^{int}-1\right)\right) - \gamma_W\left(\Omega_t^{int}-1\right) - 1\right],$$

where

$$\Omega_t^{ind} = \frac{W_t}{\pi_t^{\varphi} W_{t-1}},$$

$\varphi$ captures indexation of nominal wages to inflation, $\phi_W$ captures the convexity of adjustment costs, and $\gamma_W$ controls the asymmetry (specifically, $\gamma_W < 0$ implies it is costlier to reduce than increase nominal wages).

We consider only a symmetric equilibrium where nominal wages do not depend on $j$, leading to the wage Phillips curve

$$\begin{aligned} 0 \quad = \quad & \theta_W\left(\frac{\chi l_t^{\nu}}{w_t}\right) - \left(\theta_W - 1\right)\left(1 + \tau_W - \psi_t\left(\Omega_t^{ind}\right)\right) - \frac{\pi_{W,t}}{\pi_t^{\varphi}}\frac{\phi_W}{\gamma_W}\left[\exp\left(\gamma_W\left(\Omega_t^{ind}-1\right)\right) - 1\right] + \\ & \beta E_t\left[\frac{U_c\left(t+1\right)}{U_c\left(t\right)}\frac{\pi_{W,t+1}^2}{\pi_{t+1}^{1+\varphi}}\frac{l_{t+1}}{l_t}\frac{\phi_W}{\gamma_W}\left[\exp\left(\gamma_W\left(\Omega_{t+1}^{ind}-1\right)\right) - 1\right]\right] \end{aligned}$$

with wage inflation $\pi_{W,t} = \frac{W_t}{W_{t-1}}$.

If wages are costless to adjust ($\phi_W = 0$) then the real wage equals the disutility of labor times a constant markup,

$$w_t = \frac{\theta_W}{\theta_W - 1}\frac{1}{1+\tau_W}\chi l_t^{\nu},$$

we set $\tau_W = 1/\left(\theta_W - 1\right)$ to eliminate the monopoly distortion under flexible wages. In general, the evolution of the real wage is determined the gap between wage inflation and price inflation,

$$w_t = \frac{\pi_{W,t}}{\pi t} w_{t-1}.$$

We also need to modify the market clearing condition for composite consumption goods to account for the resources lost via wage adjustment

$$Y_t - \phi\left(\pi_t\right) Y_t - w_t L_t \psi_t\left(\Omega_t^{int}\right) = C_t + X_t + q_t\left(K_{t+1} - K_t\right).$$

There are three more parameters to be calibrated, $\phi_W$, $\theta_W$ and $\gamma_W$, in this extension. We set $\phi_W = 32$, $\theta_W = 3.5$ as in **?**, and focus on a small downward wage asymmetry $\gamma_W = -20$ for the illustrative purpose. The wage indexation parameter is set as $\varphi = 0$, reflecting the presence of nominal wage rigidity.

# 5 Model solution

We solve the model using a global solution method. This allows us to analyze both 'normal' business cycles and 'crises', when the 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).

# 6 Comparing Exchange Rate Regimes

## 6.1 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 agents wish to borrow on average, 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 (or wage) stickiness is absent. Then, from (10), we can establish that in the steady state the Lagrange multiplier on the collateral constraint is 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, reducing $Y_F$, which also reduces the marginal product of labor. 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 reduces the marginal product of capital in the steady state, thus reducing $q$. Putting these parts together gives a steady state collateral constraint

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

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, 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)

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

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

Figure **??** illustrates the determination of $e$ and $-b^*$ in the steady state. A permanent easing of the collateral constraint ( a rise in $\kappa$) will shift up the locus representing (26), raising both $e$ and $-b^*$. A higher domestic productivity will shift up both (26) and (**??**), and for our calibration, 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.

In a stochastic equilibrium, as we show below, 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 higher external debt and a higher real exchange rate.

## 6.2 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

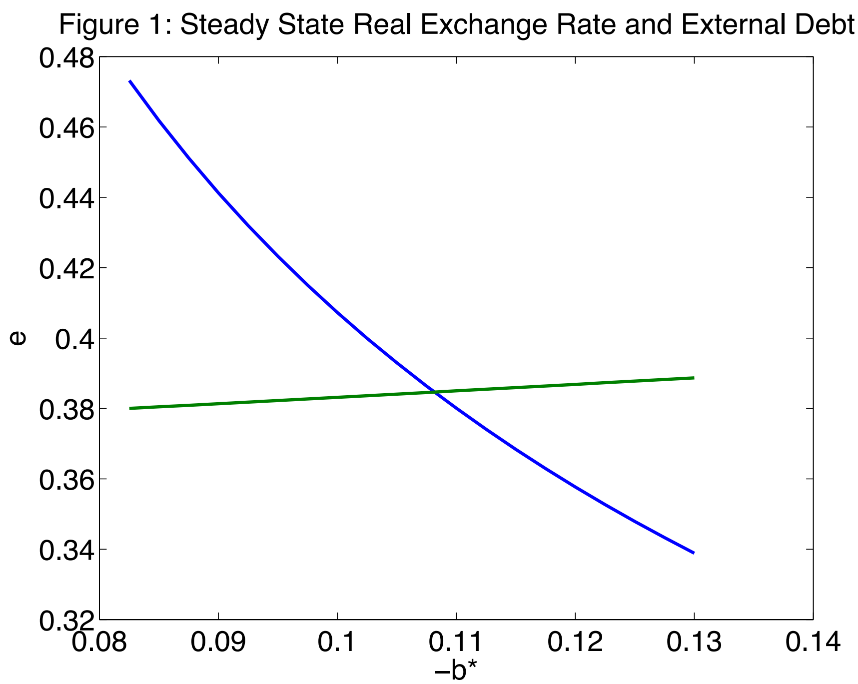


Figure 1: Debt and Real Exchange Rate determination in the steady state. The blue (downward sloping) locus is the steady state financial constraint. The green (upward sloping) locus is the steady state balance of payments condition.

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 with sticky prices has only one endogenous state variable, the level of net foreign assets $b_t^*$, and three exogenous states, represented by the shocks ($\kappa_t$, $a_t$ and $R_t^*$). We illustrate the equilibrium policy functions in Figure 2. The Figure gives the mapping from the level of net foreign debt $-b_t^*$ to output, the price of capital, the rate of inflation, the interest rate, and the real exchange rate. Since there are 8 possible exogenous states of the world in the Markov chain over the three shocks, there is a separate mapping for all 8 possible outcomes. For clarity, we show the mapping for the ‘worst state’, representing the lowest value for $\kappa_t$, 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).

The Figure 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. Intuitively, the higher external debt depresses domestic consumption demand, leading to a rise in the real exchange rate, reducing the purchase of intermediate imports, which leads to a fall in domestic production, and through a fall in the return on capital, reduces the price of capital.

A further rise in net external debt leads the collateral constraint to bind and the economy enters the crisis zone. This occurs at a debt to GDP ratio of 43% in state 1 and 56%in state 8. With the binding constraint, the kink in the policy rules indicate that the price of capital falls more quickly as net external debt rises. This further tightens the collateral constraint, 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

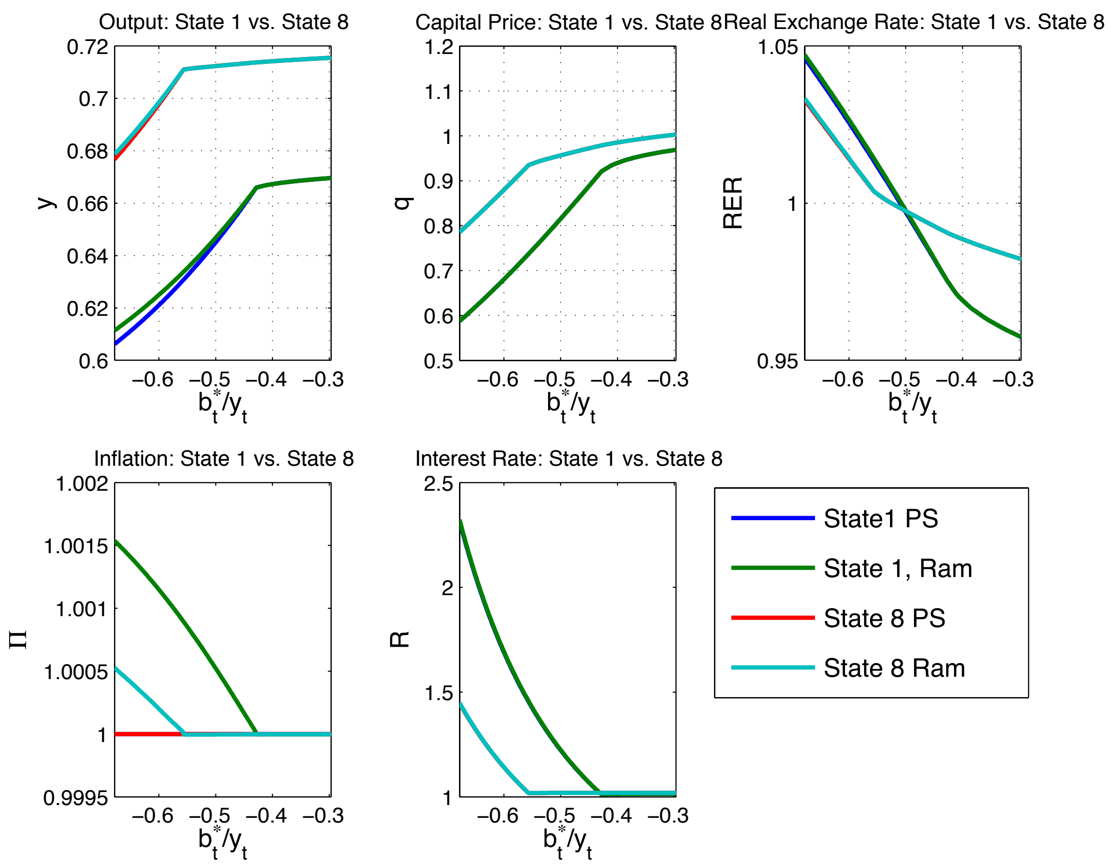


Figure 2: Equilibrium policy functions for the regime of Price Stability and Ramsey Optimal Policy.

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 policy maker 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), and 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. As we will see in section 7 below, the gain from active monetary policy may be substantially greater in an economy with both simultaneous price and wage rigidity.

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 entering this zone of vulnerability. But a key feature of Figure **??** is that it establishes that there is no 'macro-prudential' 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.

## 6.3 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.

## 6.4 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 states 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 are, and in addition, for clarity, we show the value of the Lagrange multiplier $\mu$, 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 $-b_t^*$. 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 a moment ago. 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 behaviour 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 behaviour 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 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 occurs (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-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 .2 to .5. With the lowest value of $e_{t-1}$, the range of crisis vulnerability is much smaller.

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

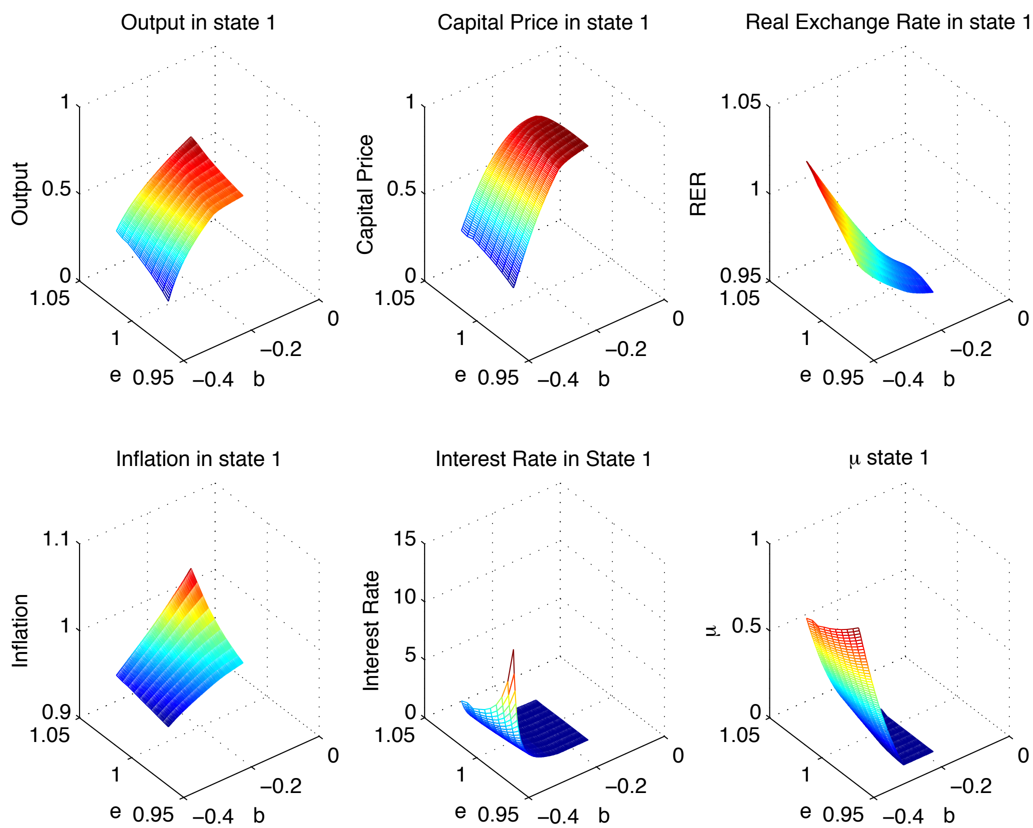


Figure 3: Equilibrium policy functions for the Pegged Exchange Rate regime in State 1.

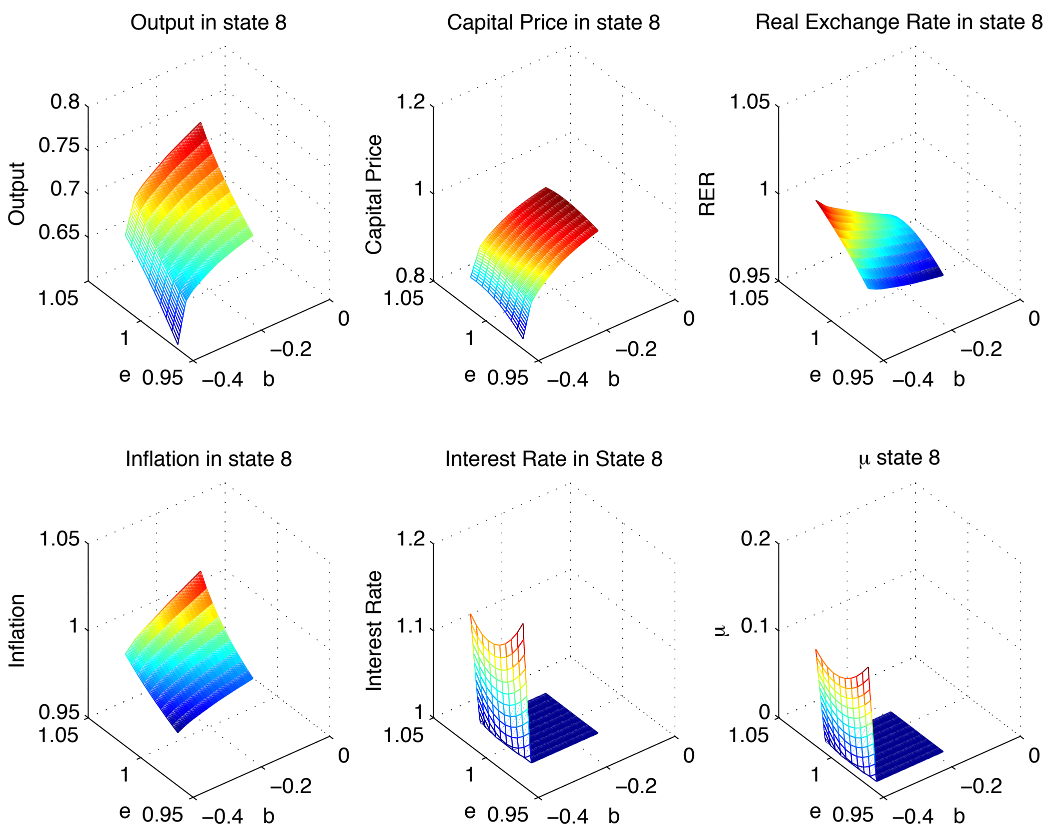


Figure 4: Equilibrium policy functions for the Pegged Exchange Rate regime in State 8.

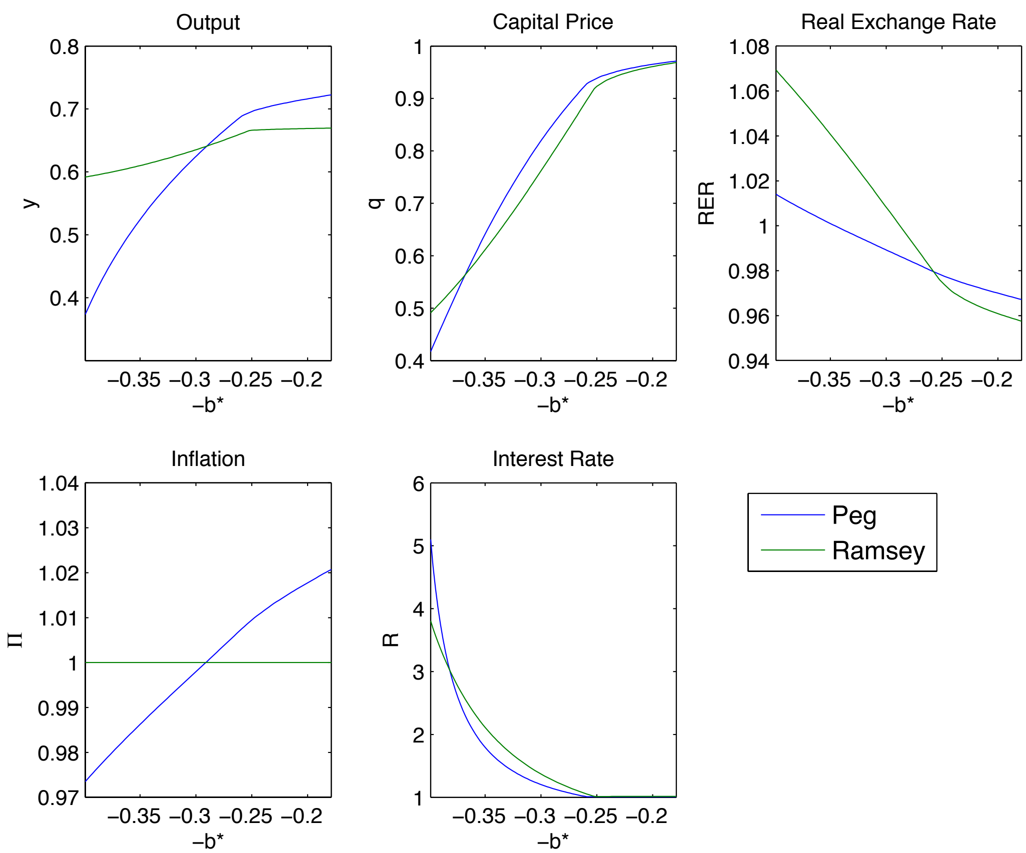


Figure 5: Policy function projection for the Pegged Exchange Rate, compared to the Ramsey Optimal policy function.

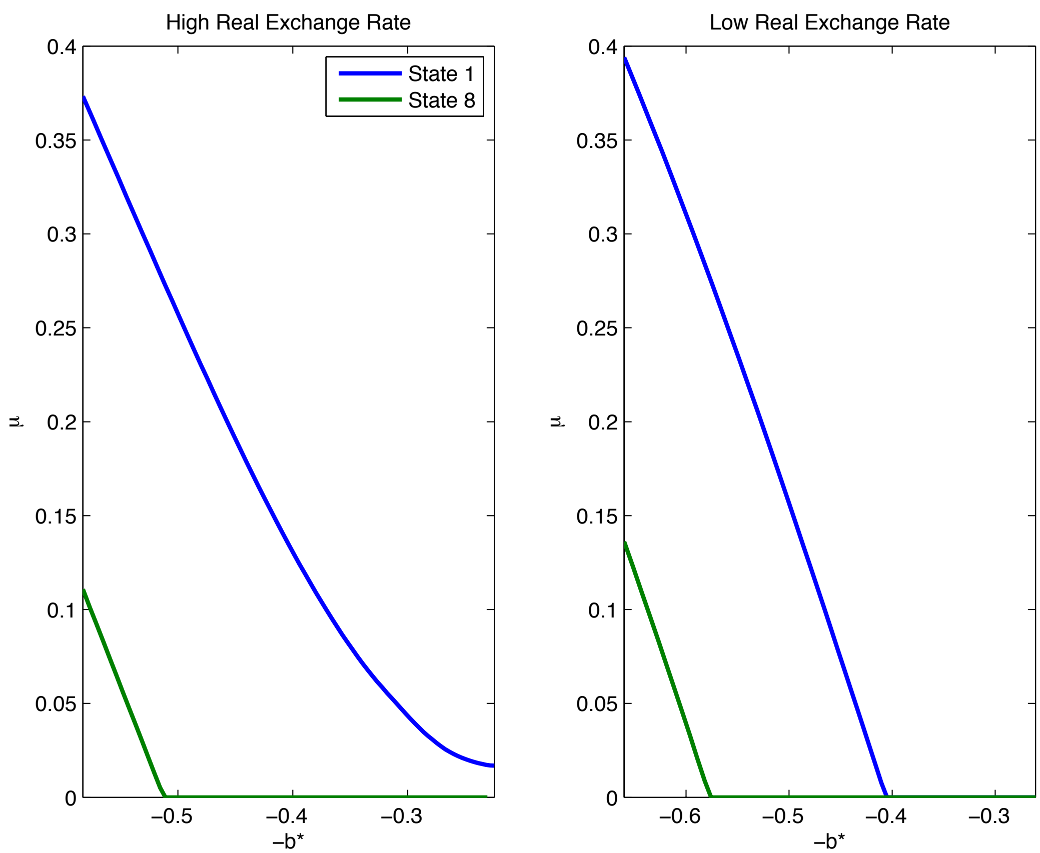


Figure 6: Debt zone of crisis vulnerability for high and low real exchange rate states in the Pegged Exchange Rate Regime.

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.[14] 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, leading to a substantially greater fall in domestic absorption. The mean level of external debt during a crisis is 10 percent 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 constrained. In a crisis, the average domestic interest rate rises to 10 percent under the floating regimes, but it rises to 17 percent 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

[14]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.

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 percent. The Ramsey Optimal policy does slightly reduces 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. [15]

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 is in place, when countries are hit by binding borrowing constraints, crises are associated with sharp downturns and a process of de-leveraging. But the depth of the downturn is crucially linked to the exchange rate regime. If the policy-maker maintains a pegged exchange rate when a crisis hits, it has a much more damaging effect.

### 6.5 Crisis Events

To see more clearly what happens in a typical financial crisis, we illustrative 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, 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 indicating a much greater rise in the external finance premium.

[15] 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

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

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

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

This is reflected in a larger increase in the domestic interest rate. The interest rate rises to 18 percent in the floating regimes, but almost twice that 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. 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 percent under the peg compared with approximately 3 percent 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, further increasing the external finance premium through the 'financial accelerator' process.

# 7 Wage and Price Stickiness

We now explore the extension of the model to both wage and price stickiness. In the previous section, we found that the model with price stickiness alone offers little benefit from an active monetary policy compared with simply stabilizing the inflation rate. Although monetary policy deviates from price stability during a crisis, its impact is quite slight. But in the previous model there is only one source of nominal rigidity; firms face a quadratic cost of price adjustment. A policy which stabilizes the aggregate CPI effectively stabilizes the firm's markup and ensures the economy operates at the flexible price equilibrium. Although the flexible price equilibrium is suboptimal, due to the presence of financial frictions as described above, the gain from deviation from price stability is of second order.

This model is as described in section 4 above. The solution now involves two endogenous state variables, the lagged real wage and the opening level of external debt. [16]

We describe the policy functions in Figures 9 and 10 for the price stability policy and the optimal Ramsey rule, respectively, where we focus on state 1 as defined previously. In contrast to the previous section, is now apparent that there is a substantial difference between the two monetary rules. The negative relationship between net external debt and output when the collateral constraint binds is significantly more extreme in the regime without the optimal monetary response. The external finance premium (measured by the Lagrange multiplier) rises significantly more under

[16] Note that in this section we compare only the price stability rule and the optimal Ramsey rule within a floating exchange rate regime. The extension to the fixed exchange rate environment involves a solution with three endogenous state variables and is currently beyond the scope of the solution algorithm.

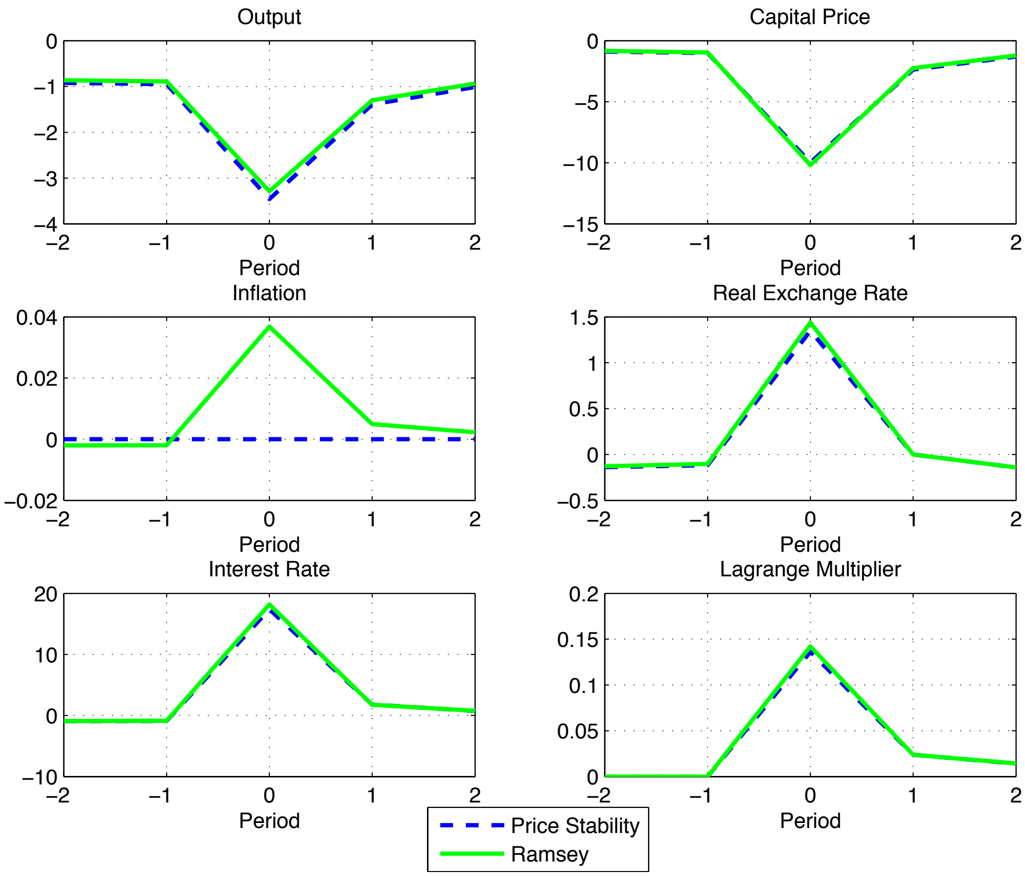


Figure 7: Crisis events for the Price Stability regime and the Ramsey Optimal policy.

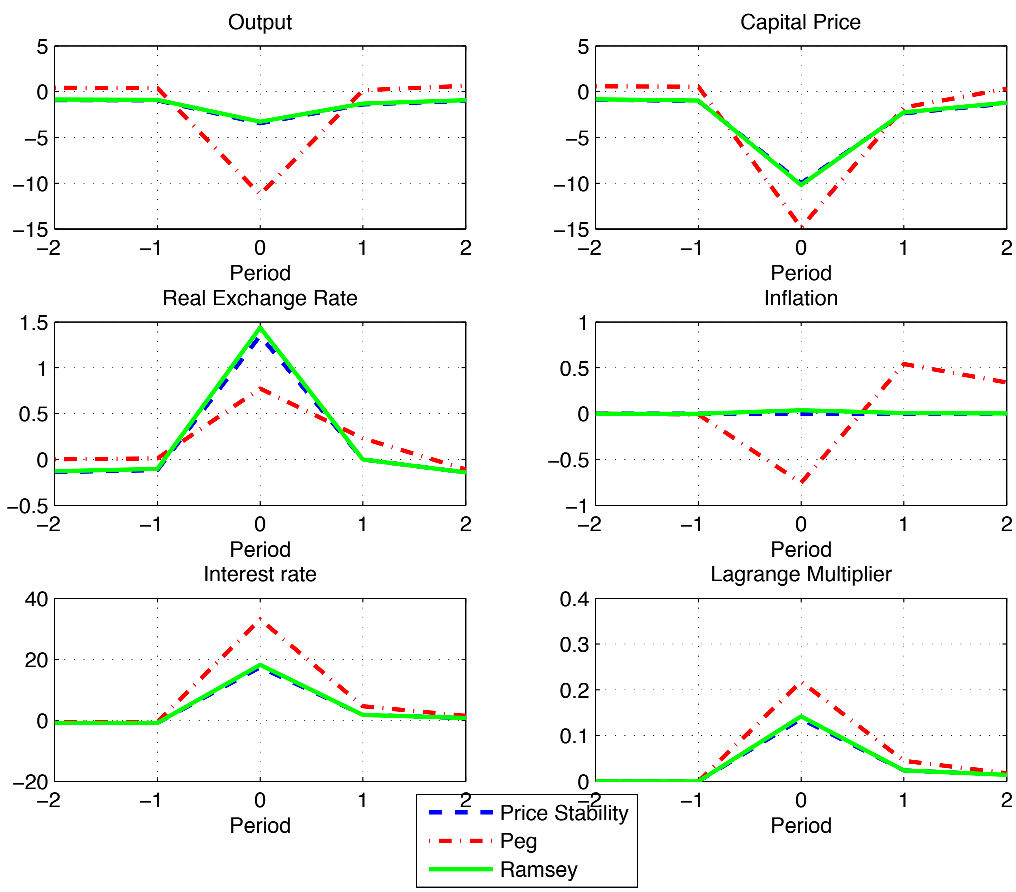


Figure 8: Crisis events for the Price Stability regime, the Ramsey Optimal policy, and the Pegged Exchange Rate regime.

the pure price stability policy, and this is reflected in a larger rise in the interest rate, and a greater fall in the price of capital. Thus, active monetary policy plays a more significant role in crisis alleviation when there are multiple sources of nominal rigidity.

Figure 11 expands on this insight. Here, we show the relationship between net external debt and the inflation rate in the optimal monetary policy regime, for the highest and lowest outcome for the wage distribution respectively. As before, we see that inflation will increase as external debt rises and the collateral constraint begins to bind. But in contrast to section 6 above, the inflation rate rises even before the collateral constraint binds. For a given level of the wage, higher external debt tends to be contractionary, and is countered by a more expansionary monetary policy. Moreover, the stance of monetary policy is substantially dependent on the predetermined wage. For the highest (lowest) wage outcome, inflation is positive (negative).

Figure 12 shows the zone of vulnerability to crises, as before, as a function of debt-to-GDP for the highest and lowest point in the wage distribution. The range of the zone depends only slightly on the level of the wage, and the range of vulnerability is very similar to that in the model without wage rigidity. While monetary policy is active outside the crisis zone in this version of the model, it should be noted that it still does not take on a 'macro-prudential' character. As external debt rises towards the threshold where a crisis is likely, monetary policy in fact becomes more expansionary, as illustrated in Figure 11.

Table 4 and 5 report the simulation mean and standard deviations from the model with wage and price stickiness. As before, we find there is little difference in means over the whole sample, while in a crisis episode, the mean levels of output, and the price of capital are substantially higher in the Ramsey equilibrium, while the mean interest rate and external finance premium are lower. In addition, the extent of deleveraging implied by the crisis is less in the Ramsey equilibrium, illustrated by a higher average debt-GDP ratio during crisis times.

In the comparison of volatilities, we find an interesting contrast with the previous section; the Ramsey optimal monetary policy has a substantial effect on macro volatility even outside of crisis times. Output and consumption volatility are significantly lower across the whole sample. Moreover, when we focus specifically on crisis episodes, we see an even bigger impact of the optimal monetary policy. In the sample where the constraint is binding, output volatility under the Ramsey equilibrium is approximately half that under the price stability rule.

Finally Figure 13 reports the 'event analysis' responses contrasting the effect of a crisis under the price stability rule with the Ramsey policy under wage and price stickiness. Here we see again substantial difference between the two rules. The Ramsey policy acts to substantially reduce the severity of crises. It does this by a highly accommodating inflationary response to the crisis, and a larger real appreciation when the collateral constraint begins to bind.

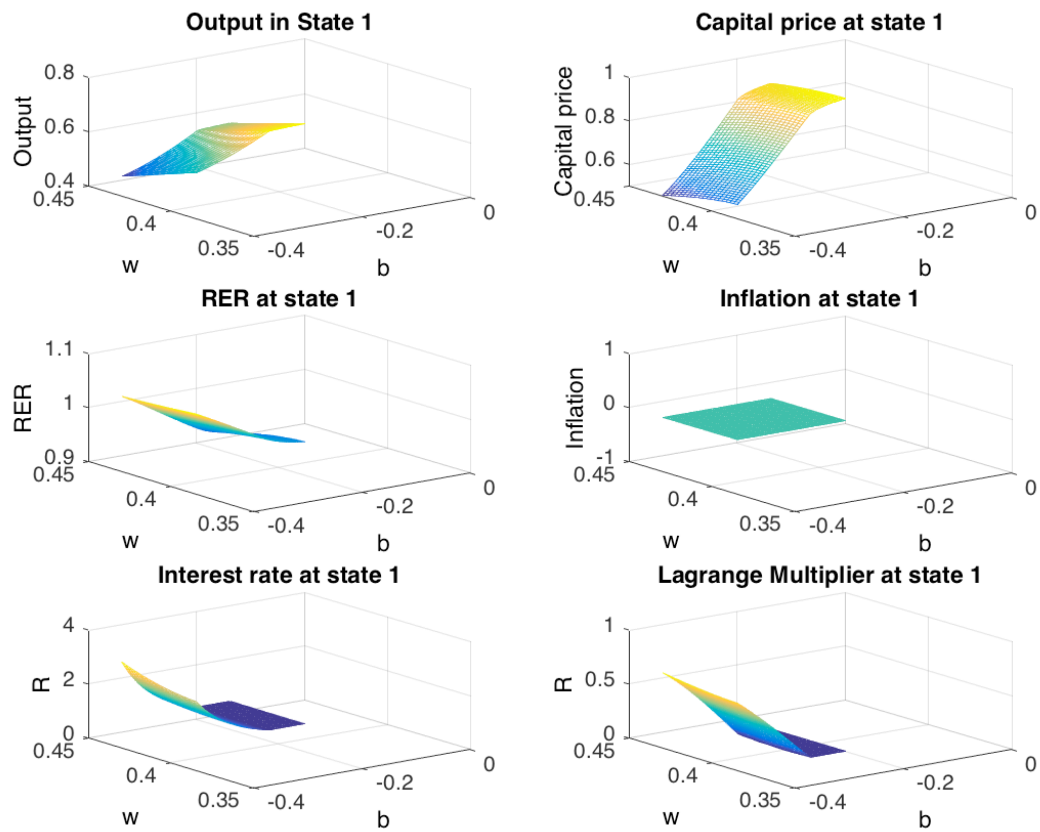


Figure 9: Policy functions for the sticky price and wage economy under the Price Stability regime.

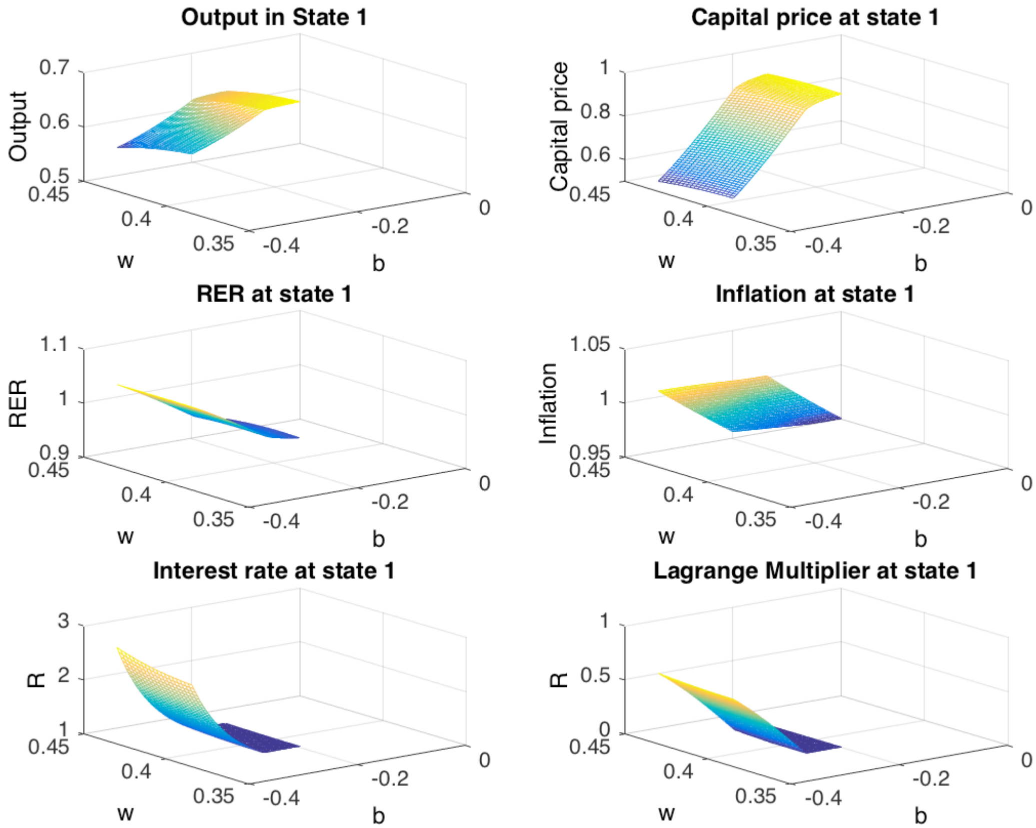


Figure 10: Policy functions for the sticky price and wage economy under the Ramsey Optimal policy.

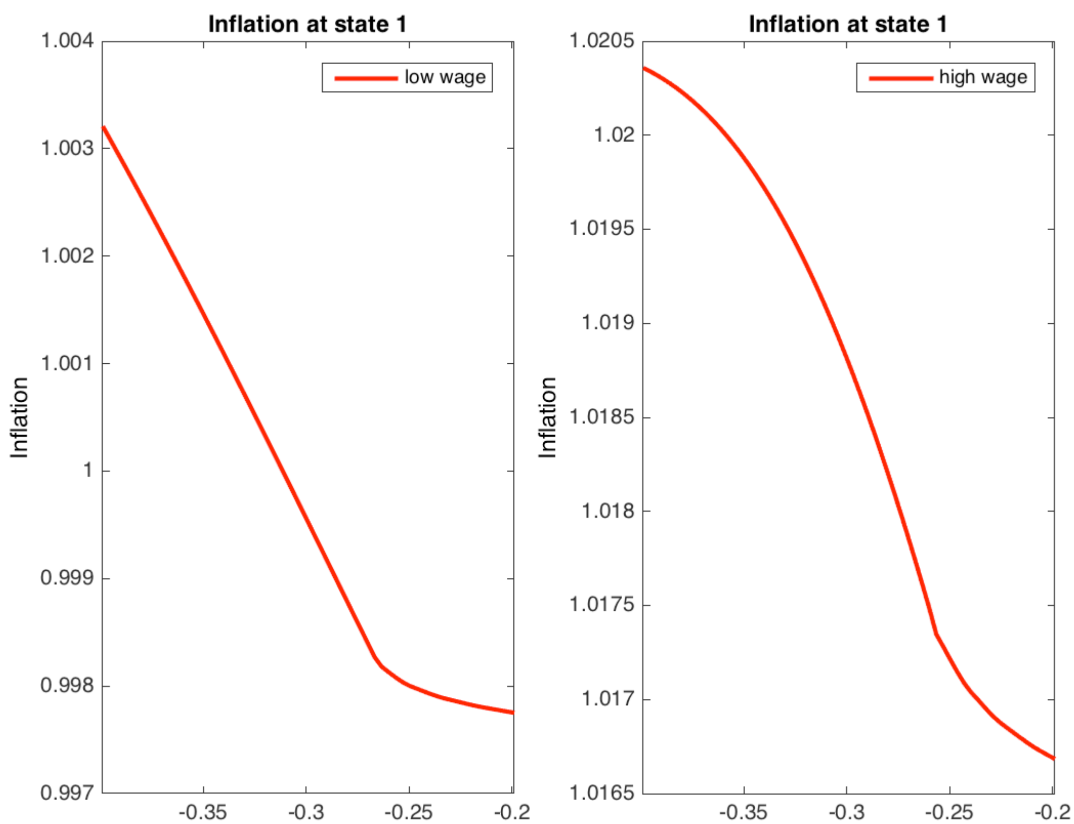


Figure 11: Inflation policy function for the sticky price and wage economy under highest and lowest outcome of the wage distribution.

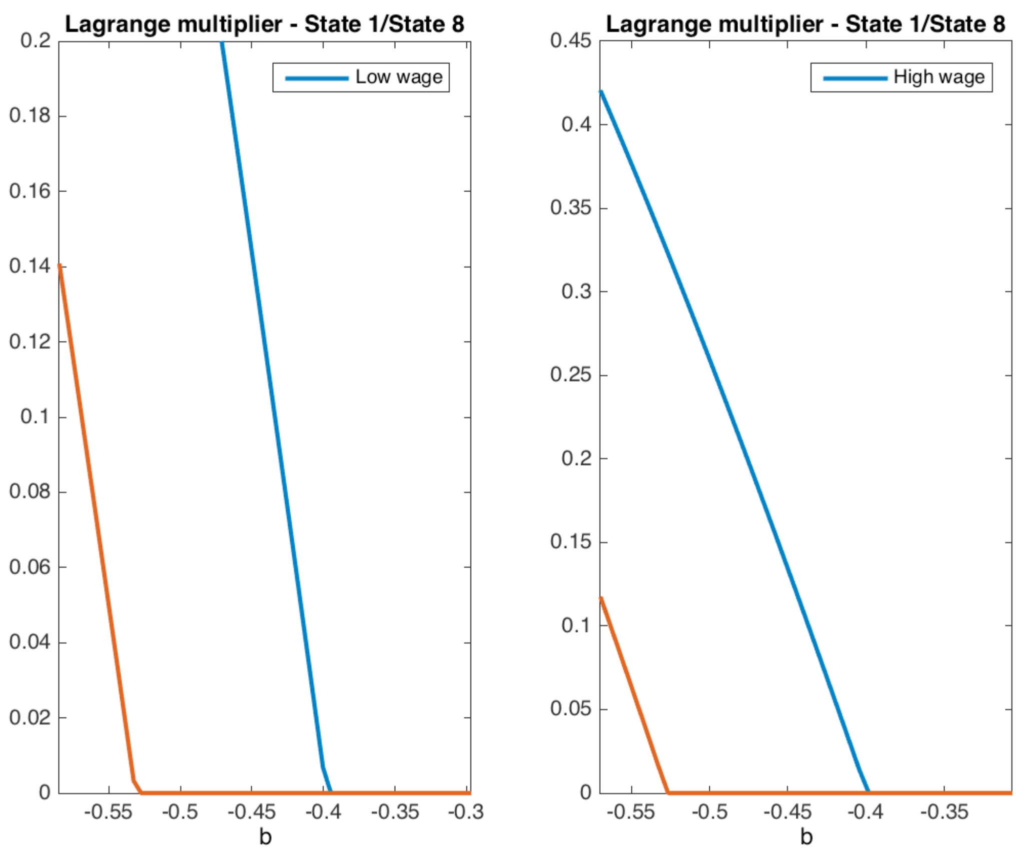


Figure 12: Lagrange multiplier bounds on the zone of vulnerability to crises for the highest and lowest outcome of the wage distribution in the sticky price and wage economy.

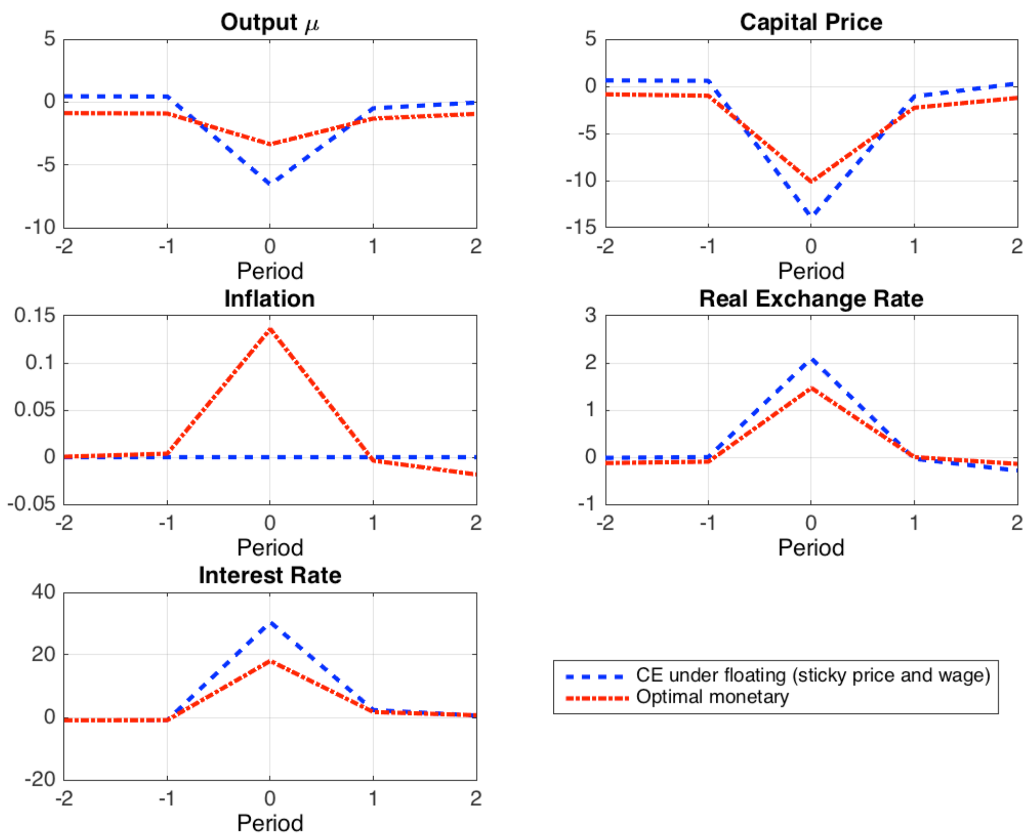


Figure 13: Crisis events in the sticky price and wage economy.

Table 4: Model moments with sticky prices and wages: Price Stability, Ramsey optimum

| Mean | | |
|---|---|---|
| | Price Stability | Ramsey |
| Probability of crisis | 6.8 | 1.07 |
| Conditional Welfare | 0.38895 | 0.3897 |
| *Panel A: the whole sample* | | |
| Output | 0.6878 | 0.6876 |
| Debt-GDP | 0.463 | 0.462 |
| Capital Price | 0.9357 | 0.9363 |
| Domestic Interest Rate | 1.025 | 1.025 |
| External Finance Premium | $0.73.e^{-2}$ | $0.74.e^{-2}$ |
| *Panel B: the subsample with binding constraints* | | |
| Output | 0.6558 | 0.6648 |
| Debt-GDP | 0.422 | 0.458 |
| Capital Price | 0.8653 | 0.8737 |
| Domestic Interest Rate | 1.16 | 1.11 |
| External Finance Premium | $1.07.e^{-1}$ | $0.64.e^{-1}$ |

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 5: Model moments with sticky prices and wages: Price Stability, Ramsey optimum

| Standard Deviation | | |
|---|---|---|
| | Price Stability | Ramsey |
| *Panel A: the whole sample* | | |
| Output | 2.67 | 1.87 |
| Consumption | 2.29 | 1.67 |
| Real Exchange Rate | 0.75 | 0.68 |
| Inflation | 0 | 0.15 |
| Capital Price | 3.49 | 3.4 |
| *Panel B: the subsample with binding constraints* | | |
| Output | 3.45 | 1.84 |
| Consumption | 4.18 | 2.59 |
| Real Exchange Rate | 1.32 | 1.19 |
| Inflation | 0 | 0.13 |
| Capital Price | 7.36 | 5.79 |

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.

# 8 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 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 $\widetilde{C(b_0^*, Z_0)}$ in a policy regime conditional on an initial state $(b_0^*, Z_0)$ as

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

Rearranging the equation yields

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

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

The unconditional welfare 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.