Exchange Rate Adjustment in Financial Crises*

Michael B. Devereux† Changhua Yu‡

University of British Columbia Peking University

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Abstract

This paper studies the positive and normative effects of alternative monetary and exchange rate polices in a small open economy model subject to occasional 'sudden stops' associated with binding borrowing constraints. Borrowing constraints in the model depend on endogenous movements in asset prices. We find that in normal times, there is little difference between alternative exchange rate policies. But during a crisis, macroeconomic outcomes are far worse under a pegged exchange rate regime. Under some shock configurations, crises may be less frequent under a pegged exchange rate regime, but the worse performance during a crisis leads the pegged exchange regime to be inferior to the floating regimes. Finally, we show that in the presence of pecuniary externalities in asset prices, there may be a case for a fiscal authority to subsidize capital inflows at a constant rate. But the benefits of capital inflow subsidies are much weaker under pegged exchange rates.

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

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†Vancouver school of economics, University of British Columbia, NBER and CEPR. Address: 6000 Iona Drive, Vancouver, BC Canada V6T 1L4. E-mail: devm@mail.ubc.ca

‡China Center for Economic Research, National School of Development, Peking University, 5 Yiheyuan Rd, Haidian, Beijing, China, 100871. E-mail: changhuay@gmail.com.

1 Introduction

In the 1990's many economists criticized emerging market countries for their unwillingness to allow exchange rates to adjust. The 'fear of floating' was seen as severe distortion in the international monetary system, and a hindrance to good macroeconomic policy for these countries. In the worst case, a persistent defence of an exchange rate peg could lead to over-borrowing and precipitate currency and financial crises, as witnessed in Asia in 1997/98. According to Obstfeld and Rogoff (1995), exchange rate flexibility should be a key part of the macroeconomic adjustment process for open economies with liberalized capital accounts. In recent years, many emerging economies have in fact moved much more towards flexible exchange rate regimes. But the experience with volatile exchange rates has been decidedly mixed. As has long been acknowledged, even in advanced economies, exchange rates tend to overshoot, and wide movements in real exchange rates may in fact exacerbate rather than alleviate the impact of external macroeconomic shocks.

For emerging economies, the lesson is the same, only more-so. In many instances, highly volatile capital flows have led to huge swings in real exchange rates, as recently witnessed in Brazil and Russia. It is questionable whether exchange rate adjustment can be a very useful feature of macro policy in these countries. As argued in Rey (2013, 2015), flexible exchange rates may play little role in facilitating an independent monetary policy when capital flows are driven by large external shocks. In particular, emerging economies are excessively vulnerable to the 'global financial cycle', which can cause unstable inflows and outflows of capital and associated boom and contraction in exchange rates, asset prices, credit and real economic activity.

These observations call for a rethinking of the role of the exchange rate and monetary policy in crisis-prone emerging countries. What survives of the validity of the traditional Mundell-Fleming trilemma? Is it possible to have any monetary policy autonomy in emerging economies, even with flexible exchange rates? Given the history of financial crises in emerging market economies, and excessive vulnerability to global capital flows, is it realistic to expect exchange rate movements to play a large role in macroeconomic adjustment? Additional policy tools, such as capital controls, have been endorsed by international organizations and deployed by many countries in various circumstances. On the other hand, a large number of emerging and developing countries still stuck to a currency peg during and after the global financial crisis (Reinhart and Rogoff, 2004; Rose, 2014).

There is a substantial literature on capital market crises in emerging market countries (see below for a review). A key feature of emerging markets that differentiate them from advanced economies is the prevalence of 'sudden stops' in capital market access. These sudden reversals of capital flows have been associated with large financial and economic crises. The existing literature on sudden stops stresses the non-linear dynamics associated with crises, but for the most part (see below for references) has not integrated the modeling with the investigation of monetary policy or the exchange rate regime. But recent experience has made this a first order question. If emerging economies sudden stop episodes are driven solely by structural financial accelerator dynamics and independent of monetary policy stance, and moreover, are essentially impervious to alternative monetary policy rules, then the consequences for open capital markets are much more serious, since it implies that the only effective tools for insulating an economy from external funding shocks are controls on capital flows. But if the exchange rate regime can play an important role in responding to capital flow shocks, then the policy implications may be very different.

This paper explores the benefits of nominal exchange rate adjustment in a small economy which is vulnerable to 'sudden stop' financial crises associated with occasionally binding borrowing constraints. We contrast a policy of an exchange rate peg with a flexible inflation targeting monetary rule, a Ramsey optimal monetary policy, and a policy that makes use of both monetary policy and capital controls. The analysis is carried out in a stochastic environment using a global solution technique, assuming that the economy is vulnerable to domestic and external shocks, as well as unpredictable reversals in international capital flows. Our aim is to revisit the debate on the open economy 'Trilemma', asking to what extent nominal exchange rate adjustment can assist in dealing with sudden stop crises in emerging market economies.

The key technical novelty of the paper is to combine global solution methods for a small economy that is subject to occasionally binding borrowing constraints, with a sticky price New Keynesian model. This allows us to look at the effect of alternative monetary policy rules on the incidence and severity of financial crises. The main appeal of the modelling strategy is the fact that the analysis is carried out within a full global stochastic environment. In addition, we can use the model to derive the characteristics of an optimal monetary policy within this environment. We characterize the optimal monetary policy in both 'normal times' when the economy is far away from a binding borrowing constraint, and in 'crisis times', when the borrowing constraint tightly binds. In addition, we can ask how alternative monetary rules affect the frequency and severity of financial crises.

Our results can be summarized briefly. In 'normal times', when the economy operates away from a binding borrowing constraint, the difference between an exchange rate peg and an optimal monetary policy (or a flexible inflation target) is very slight, both in terms of macroeconomic indicators and welfare. But in crises, nominal exchange rate adjustment can play a large and beneficial role, substantially reducing the negative impact of capital flow reversals as well as substantially improving conditional welfare. During a sudden stop crisis in a pegged exchange rate regime, the economy experiences a rapid deflationary episode, followed by a burst of inflation. This can be largely avoided by an appropriately designed monetary policy under floating exchange rates. Real interest rates rise much more in a pegged exchange rate regime following a sudden stop than under a float. As a result, the real effects of binding borrowing constraints are much more serious for a pegged exchange rate regime, leading to greater losses in consumption, output and employment. Thus, the paper contributes to the growing literature on sudden stop crises by illustrating the importance of monetary and exchange rate policy in responding to crises.

Our results also suggest that there is little effectiveness in using monetary policy to target financial indicators (such as asset prices or credit volumes) during normal times so as to reduce the possibility of future crises. The optimal monetary policy in our environment is described much more as a 'mopping up' response, after a crisis, rather than a precautionary tool to avoid the incidence of crises.

A later section of the paper explores the case for levying capital inflow taxes or subsidies in light of the risk of sudden stops. Under a floating exchange rate regime, we find that a constant capital inflow subsidy can enhance welfare by exploiting the presence of positive pecuniary externalities in the pricing of collateral assets. Under a pegged exchange rate regime, by contrast, the benefits of a capital inflow subsidy are much smaller, since it raises the costs of sudden stop crises, because it increases the stationary distribution of external debt, and increases the severity of crises.

While the paper is mainly a theoretical analysis, the results suggest that the recent pessimism about the usefulness of exchange rate flexibility for emerging economies may be overdone. While it is clear that the policy issues raised by volatile capital flows and sudden stops present a very different and more serious set of problems for emerging economies than those faced by policy making in advanced economies, it is still the case that monetary policy can play a substantial role in responding to capital market crises. Moreover, efficient exchange rate adjustment plays a crucial role during a crisis.

The paper is organized as follows. The next section discusses the relevant literature. Section 2 describes the details of the small open economy model. Section 3 and 4 describe respectively the calibration and computational solution of the stochastic model. Section 5 presents the main comparisons of alternative exchange rate and monetary policy rules. Section 6 describes extensions to allow for capital inflow subsidies in the model. Section 7 presents some brief conclusions.

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.

2 The model

We consider a small open economy. The baseline model structure is similar to Devereux, Young and Yu (2015), which is built upon Cespedes, Chang and Velasco (2004) and Mendoza (2010). In this small economy, there exist infinitely lived firm-households with a unit measure, who own all domestic firms. International financial markets are incomplete. Households trade assets across borders only in foreign currency denominated non-state contingent bonds. There are two types of domestic producers: competitive wholesale goods producers and monopolistically competitive final goods producers. Wholesale producers combine imported intermediate inputs, domestic labor and physical capital in competitive factor markets

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

with $\alpha_F + \alpha_L + \alpha_K \leq 1$. M_t denotes the 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, with a constant elasticity of substitution technology given by

$$Y_{F,t} = \left(\int_0^1 \left(Y_{F,t}(i)\right)^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}}, \tag{2}$$

where θ stands for the elasticity of substitution between imported varieties. In this small open economy, prices in the rest of world are exogenously given. For simplicity but without loss of generality, we assume that foreign currency denominated prices of all intermediate varieties are identical so that $P^*_{F,t} = P^*_{F,t}(i)$ in the rest of world.

As will be described below, wholesale goods produced in the domestic economy are themselves combined to produce a final consumption good which is consumed both by domestic households and by foreign consumers. We posit an exogenous foreign demand function for the domestic consumption composite, X_t, given by

$$X_t = \left(\frac{P_t}{\mathcal{E}_t P^*_t}\right)^{-\rho} \zeta^*_t, \tag{3}$$

where P_t is the price of the domestic good, and $\mathcal{E}_t$ 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. Note that the share of expenditures in the foreign country (the rest of world) on imports from the domestic country is assumed to be too small to be taken into account in 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 Firm-households

In the domestic economy the representative infinitely lived firm-household has a form of preferences given by

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t, l_t), \tag{4}$$

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 is a net debtor. Current utility function takes a GHH (Greenwood, Hercowitz and Huffman, 1988) form [1]

$$U(c_t, l_t) = \frac{\left(c_t - \chi \frac{l_t^{1+\nu}}{1+\nu}\right)^{1-\sigma} - 1}{1-\sigma}. \tag{5}$$

Similar to Mendoza (2010), households borrow from abroad to finance both imported intermediate inputs and consumption. Assume that borrowing is denominated in foreign currency and that total borrowing from abroad requires physical capital k_{t+1} as collateral, due to agency costs associated with imperfect contract enforcement. Hence the collateral (or borrowing) constraint can be written as

$$\vartheta(1+\tau_{N,t})Y_{F,t} - B^*_{t+1} \leq \kappa_t E_t \left\{ \frac{Q_{t+1}k_{t+1}}{\mathcal{E}_{t+1}} \right\}, \tag{6}$$

where B^*_{t+1} stands for domestic 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. Parameter κ_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 all domestic firms equally and they make identical decisions in a symmetric equilibrium. A representative firm-household faces the following budget constraint

$$P_t c_t + Q_t k_{t+1} + \frac{B_{t+1}}{R_{t+1}} + \frac{(1-\tau_{c,t})B^*_{t+1}\mathcal{E}_t}{R^*_{t+1}} \leq W_t l_t + k_t(R_{K,t} + Q_t) + B_t + B^*_t \mathcal{E}_t + T_t$$

$$+ \left[P_{M,t}M(Y_{F,t}, L_t, K_t) - (1+\tau_{N,t})Y_{F,t}\mathcal{E}_t - W_t L_t - R_{K,t}K_t\right] + D_t. \tag{7}$$

The left-hand side of the constraint above displays domestic consumption expenditure $P_t c_t$, capital purchase $Q_t k_{t+1}$, 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}. The right-hand side 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

[1] This form of preference simplifies the computational procedure for the model, but does not play a key role in the qualitative analysis.

from government T_t, profits from wholesale good producers $P_{M,t}M_t-(1+\tau_{N,t})Y_{F,t}\mathcal{E}_t-W_tL_t-R_{K,t}K_t$ 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 (6). A lower case price variable denotes the real price, i.e., $q_t = Q_t/P_t$, $w_t = W_t/P_t$. The consumer price index inflation rate is defined as $\pi_t = P_t/P_{t-1}$ and real exchange rate 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

$$w_t = \chi l_t^{\nu}. \tag{8}$$

As is well known, given the form of preferences, households labor supply is independent of wealth effects.

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

$$q_t = \mu_t \kappa_t E_t \left\{ \frac{q_{t+1}e_t}{e_{t+1}} \right\} + E_t \left\{ \beta \frac{U_c(t+1)}{U_c(t)} (r_{K,t+1} + q_{t+1}) \right\}. \tag{9}$$

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 standard and described by

$$1 = E_t \left\{ \beta \frac{U_c(t+1)}{U_c(t)} \frac{R_{t+1}}{\pi_{t+1}} \right\}. \tag{10}$$

Finally, the choice of foreign currency bonds leads to the Euler equation as follows

$$1-\tau_{c,t}=\mu_t R^*_{t+1}+E_t\left\{\beta\frac{U_c(t+1)}{U_c(t)}\frac{e_{t+1}}{e_t}R^*_{t+1}\right\} \tag{11}$$

As in the capital Euler equation, the benefit of holding an additional unit of the foreign currency bond is enhanced if the collateral constraint (6) is binding.

We note that the combination of (10) and (11) imply that uncovered interest rate parity will not hold in this model, when $\mu_t>0$, even up to a first order approximation. This is because, when the collateral constraint binds, there is an endogenous external finance premium associated with the degree to which the constraint binds. As we show below, this external finance premium may differ systematically between exchange rate regimes. This implies that during crises, domestic interest rates may be much higher in a pegged exchange rate regime than under a floating regime.

The household-firms choice of imported inputs, labor and capital are expressed as

$$p_{M,t}\frac{\alpha_F M_t}{Y_{F,t}}=e_t\left(1+\vartheta\mu_t\right)\left(1+\tau_{N,t}\right), \tag{12}$$

$$p_{M,t}\frac{\alpha_L M_t}{L_t}=w_t \tag{13}$$

$$p_{M,t}\frac{\alpha_K M_t}{K_t}=r_{K,t}. \tag{14}$$

where w_t denotes the cost of labor.

Note that condition (12) implies that the 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 production.

The complementary slackness condition related by (6) is written as

$$\mu_t\left[\kappa_t E_t\left(\frac{q_{t+1}k_{t+1}}{e_{t+1}}\right)+b^*_{t+1}-\vartheta Y_{F,t}(1+\tau_{N,t})\right]=0, \tag{15}$$

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 of which differentiates wholesale goods into a variety of final goods. Each variety is an imperfect substitute for other varieties, implying that final good producers have monopoly power over their varieties. All consumption varieties are aggregated into the 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. $\theta > 1$ 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 $Y_t(i)$

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\theta} Y_t. \tag{16}$$

Each variety producer makes use of a linear technology

$$Y_t(i) = M_t(i). \tag{17}$$

Firms set prices in domestic currency (producer currency pricing) and can reset their prices each period, but suffer a quadratic price adjustment cost (see Rotemberg, 1982). Profits per period gained by firm i equal total revenues net of wholesale prices and of price adjustment costs, and are 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 τ_H denotes a subsidy rate by the government in order to undo the monopoly power of price setters. We assume an asymmetric price adjustment cost function, $\phi\left(\frac{P_t(i)}{P_{t-1}(i)}\right)$ following Varian (1975) and Kim and Ruge-Murcia (2009), where

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

Here π is the inflation target. In the cost function $\phi(\cdot)$, ϕ_P characterizes the 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 (16) and production technology (17). The stochastic discount factor used by the firm is given by $\Lambda_{h,t} = \beta^{t-h} U_c(t)/U_c(h)$ with $h \leq t$.

As usual, we consider a symmetric equilibrium, where all firms choose the same price, $P_t(i) = P_t$. Consequently, 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

$$\begin{aligned} & Y_t\left[(1+\tau_H) - \theta\left(1+\tau_H - p_{M,t}\right)\right] - \phi_P Y_t \pi_t \frac{\exp\left(\gamma(\pi_t - \pi)\right) - 1}{\gamma} + \\ & E_t\left[\Lambda_{t,t+1} \phi_P \pi_{t+1} Y_{t+1} \frac{\exp\left(\gamma(\pi_{t+1} - \pi)\right) - 1}{\gamma}\right] = 0. \end{aligned} \tag{18}$$

Real profits from intermediate producers are

$$\begin{aligned} d_{H,t} \equiv \frac{D_{H,t}}{P_t} &= (1+\tau_H) Y_t - p_{M,t} Y_t - \phi(\pi_t) Y_t \\ &= Y_t\left[(1+\tau_H) - p_{M,t} - \phi(\pi_t)\right]. \end{aligned} \tag{19}$$

with

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

Without nominal rigidities $\phi_P = 0$ and with appropriate 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 $l_t = L_t$, $c_t = C_t$. In the model we assume that domestic bonds can only be held by domestic agents so that $b_{t+1} = 0$ and in the aggregate, the capital stock is fixed, 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

$$\int_0^1 Y_t(i)di = \int_0^1 M_t(i)di = M_t. \tag{20}$$

Consumption composites are either consumed by domestic households or exported to the rest of world

$$Y_t \left[1 - \phi(\pi_t)\right] = C_t + X_t. \tag{21}$$

2.3 Government policy

The government makes lump-sum transfers to domestic households

$$T_t = -\tau_H Y_t P_t - \frac{\tau_{c,t} b^*_{t+1} e_t}{R^*_{t+1}} P_t + \tau_{N,t} Y_{F,t} e_t P_t. \tag{22}$$

As noted above, we assume also that the government sets a production subsidy τ_H to offset the monopoly power of price setting. The central bank implements monetary policy with either a fixed exchange rate or flexible exchange rate regime. In the regime of flexible exchange rates, monetary policy follows a strict inflation targeting policy, although we will also derive an optimal, welfare maximizing monetary policy under flexible exchange rates. The monetary rule can be defined by [2]

$$R_{t+1} = R \left(\frac{\pi_t}{\pi}\right)^{\alpha_\pi} \left(\frac{Y_t}{Y}\right)^{\alpha_Y} \left(\frac{e_t}{e}\right)^{\alpha_e}. \tag{23}$$

[2] 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.

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 is determined by foreign inflation and the change in the real exchange rate,

$$\pi_t = \frac{e_{t-1}}{e_t}\pi_t^* = \frac{e_{t-1}}{e_t}. \tag{24}$$

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 explore a 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, within a regime of flexible exchange rates. We focus on the time-consistent optimal policy under discretion and look for a Markov-perfect equilibrium. The current planner takes as given the decisions of future planners but internalizes how those choices depend on the future debt level b^*_{t+1} chosen today.

The monetary authority chooses the paths for inflation rates π_t to maximize a representative household's life-time utility. 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. The problem faced by the government reads,

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

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.[3]

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

2.5 Aggregate market clearing

Combining firm-households' budget constraints (7) with the relevant market clearing conditions and taxation policy (22), yields the country level resource constraint

$$C_t + \left(\frac{b_{t+1}^*}{R_{t+1}^*} - b_t^* \right) e_t = Y_t \left(1 - \phi(\pi_t) \right) - e_t Y_{F,t}. \tag{25}$$

Equivalently, (25) implies that trade surpluses are used to finance external debt

$$X_t - e_t Y_{F,t} = \left(\frac{b_{t+1}^*}{R_{t+1}^*} - b_t^* \right) e_t. \tag{26}$$

The current account may be expressed as

$$ca_t = X_t - e_t Y_{F,t} + \frac{e_t b_t^*}{R_t^*} (R_t^* - 1), \tag{27}$$

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 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.

3 Calibration

The model parameters are quite standard in the literature and mainly taken from Devereux, Young and Yu (2015). The model period is defined as one quarter. The subjective discount factor is set to 0.975 to generate a 10% real interest rate per annum in emerging markets. The relative risk aversion is 2, and the inverse of the Frisch labor supply elasticity is one. The parameter governing the disutility of labor supply is set as 0.4 to generate a one unit supply of labor at the steady state. We set the input share in the wholesale good production at $\alpha_F = 0.16$, the share of labor, $\alpha_L = 0.57$ and $\alpha_K = 0.03$ to match the import-GDP ratio, labor income-GDP ratio and the external debt-GDP in emerging economies. The nominal price adjustment cost and downward nominal price rigidity are set as $\phi_P = 76$ and $\gamma = -50$. We make use of a moderate working capital share $\vartheta = 0.5$ as in Devereux, Young and Yu (2015). Combined with imported input share in the production $\alpha_F = 0.16$, the model generates a working-capital GDP ratio of 10%. The elasticity of substitution among imported varieties and the elasticity of substitution in the foreign country are set the same $\theta = \rho = 10$, implying a 10% price markup within the country and across borders. The scale parameter in foreign demand is chosen to be $\zeta = 0.117$ which ensures that the real exchange rate equals one in the steady state.

The model is simulated with three stochastic shocks. We consider a domestic productivity shock, a foreign interest rate shock, and 'deleveraging' shock. The quarterly international interest rate is set to be 1.5% with persistence $\rho_R = 0.6$ and a standard deviation $\sigma_R = 0.00623$. The domestic productivity shock is normalized to be one with persistence $\rho_A = 0.95$ and standard deviation $\sigma_R = 0.008$. The leverage parameter takes two values, high $\kappa_L = 0.35$ and low $\kappa_H = 0.45$, with transition probability from high leverage to high leverage $p_{H,H} = 0.975$ and from low leverage to low leverage $p_{L,L} = 0.775$ as in (Bianchi and Mendoza, 2013). The unconditional probability of lower leverage becomes 10%. A jump of leverage from κ_H to κ_L is associated with a tighter collateral constraint.[4]

There are several policy instruments in the model. We fix $\tau_H = \frac{1}{\theta-1}$ and $\tau_{N,t} = \frac{1}{\rho-1}$ to eliminate monopolistic market power in the firm's price setting in the steady state as well as eliminating the monopoly power in the international intermediate good markets. The latter setting ensures that in choosing an optimal monetary policy, the monetary authority does not wish to manipulate the terms of trade (or real exchange rate) of the small economy to gain an advantage over foreign importers.

[4]Increasing κ_H doesn't change the results since the borrowing constraint almost never binds when $\kappa_H = 0.45$.

Table 1: Parameter values

Parameter		Values
Preference		
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
Production		
α_F	Intermediate input share in production	0.16
α_L	Labor share in production	0.57
α_K	Capital share in production	0.03
ϕ_P	Price adjustment cost	76
γ	Asymmetric price adjustment cost	-50
ϑ	Share of working capital	0.5
θ	Elasticity of substitution among imported varieties	10
ρ	Elasticity of substitution in the foreign countries	10
ζ	Steady state of foreign demand	0.117
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
Policy variables		
α_π, α_Y, α_e	Coefficients in the Taylor rule	
τ_H	Subsidy to final goods producers	$\frac{1}{\theta-1}$
$\tau_{N,t}$	Import tax rate	$\frac{1}{\rho-1}$

4 Model Solution

We solve the model using a global solution method, which enables us to analyze both 'normal time' business cycles and 'crises', when the collateral constraint binds. For the competitive equilibrium in both the floating and pegged exchange rate regimes, we make use of the standard policy function iteration approach to solve the models. For the optimal monetary policy under the floating exchange rate regime, 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 Comparing Exchange Rate Regimes

Note that the collateral constraint (6) may or may not bind, and it is determined by the inherited debt level and the exogenous shocks. The dynamics of the model exhibit a highly nonlinear pattern. When a country that has accumulated a large external debt is hit by a severe adverse shock, particularly a deleveraging shock, it faces a tighter borrowing constraint. This adverse credit condition forces the country to reduce its external borrowing substantially. Limited debt rollover in turn depresses consumption and the value of collateral (the real price of capital), which results in a cycle of curtailed international borrowing and deteriorating domestic fundamental and financial variables. Note that external borrowing is denominated in foreign currency, so it is not possible to erode the real value of debt through domestic inflation. Nevertheless, because prices are sticky, the monetary authority can stimulate domestic aggregate demand through inflation and real exchange rate depreciation. A real exchange rate depreciation causes an immediate increase in foreign demand for domestic final goods, and if the depreciation is temporary, or if the depreciation reduces the external finance premium, it leads to a reduction in the effective domestic real interest rate, increasing domestic consumption demand.

5.1 Model Results across Exchange Rate Regimes

Tables 2, 3 and 4 compare the simulation results under three alternative regimes, corresponding to a policy of strict inflation targeting, an optimal monetary policy, and a pegged exchange rate regime. In each case we report the mean and standard deviation of the main endogenous variables in the model. We do this for the full sample, and then for the separate subsample pertaining to the cases where the collateral constraint is binding (or what we call 'crisis times').

In a crisis, the binding collateral constraint forces a deleveraging, leading to a fall in consumption, output and a fall in the price of capital, which leads to a further tightening of the collateral constraint in the manner of the debt-deflation process described by Mendoza (2010). This is exacerbated by the rise in the cost of imported inputs. As described by equation (12), when the collateral constraint binds, the effective cost of borrowing needed to finance working capital rises discretely. This leads to a fall in imported intermediate inputs, which in turn further reduces the marginal product of labor and leads to a decline in employment and output.

The critical issue for our analysis is the possibility for generating a real exchange rate depreciation so as to offset the negative effects of crises.

Outside of a crisis, when the collateral constraint is slack, there is little difference between the inflation targeting regime (or optimal monetary policy) and the pegged regime. In terms of means, consumption, output and employment are 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, in order to avoid the consequences of a crisis, since as we see below, the negative effect of a crisis on household consumption is considerably larger under a pegged exchange rate regime. When we look at volatilities during normal times, there is more of a contrast between the peg and the inflation targeting regime. Obviously, 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. Interestingly, we find that output volatility is lower under the peg. This is attributable to the presence of domestic productivity shocks. When the collateral constraint doesn't bind, price stability will replicate the flexible price equilibrium. In this case productivity shocks generate a procyclical real exchange rate (a rise in output supplied requires a real exchange rate deprecation to stimulate the rise in demand). Under the pegged exchange rate regime, this can't happen so easily, due to sticky prices and the nominal exchange rate peg, so the output response to a productivity shock is dampened. If the model were to be calibrated to a higher share for leverage shocks and/or foreign interest shocks, the model under the peg would generate higher output volatility than that under inflation targeting.[5]

During normal times, there is no difference in economic outcomes between the strict inflation targeting policy and the welfare optimal monetary policy, either in means or in volatility (see Tables 2 and 3). In fact, we find that when the collateral constraint is slack, an optimal monetary policy follows exactly the same path as the strict inflation targeting regime. Domestic consumer price inflation is zero, and the price-cost markup is kept constant at zero. This immediately implies that there is no role for optimal monetary policy to play a 'macro-prudential' role, whereby the monetary authority adjusts monetary policy in advance of a possible crisis. Outside of a crisis, the optimal monetary policy is equivalent to strict inflation targeting.

We conclude therefore that there is little difference between the three alternative monetary policy regimes in the absence of crises. But the results in crisis times, when the collateral constraint is binding, are very different. Tables 2, 3 and 4 indicate that there is a large contrast in sample means and volatilities for all economic outcomes between the pegged regime and the other two monetary regimes, in states where $\mu > 0$.

In a crisis situation, under all regimes, the country is forced to delever, so that on average debt during a crisis is lower. In addition, the binding borrowing constraint raises the effective cost of intermediate imports, which leads to a fall in imports, employment and output. But the overall impact is much greater in the pegged regime. The reversal in the current account is much greater, since in the absence of rapid real exchange rate adjustment, domestic interest rates rise much more under the peg, leading to a greater fall in domestic absorption. The mean level of external debt

[5]In the online Appendix, we show that absent TFP shocks, output volatility is higher in the peg than under the inflation targeting regime.

during a crisis is 10 percent lower in a fixed exchange rate environment than under either alternative floating regime. As we saw above, outside of a crisis, interest rates in floating and fixed exchange rate regimes are identical, 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 16 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 an 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 mostly reflects the much greater external finance premium, as shown in Tables 2 and 4 .

The different properties of the peg and the floating regimes during a crisis can most easily be seen by the behavior of the price cost markup. Under a strict inflation targeting regime, the price cost markup is kept constant both in normal times and in crisis times. An optimal monetary policy allows the price cost markup to take on a countercyclical stance during a crisis. This reflects an accommodative monetary policy which leads the nominal exchange rate response to cushion the economy during the crisis. But in a pegged exchange rate regime, the price cost markup is procyclical during the crisis. To maintain the peg, the authorities must tighten monetary policy during the crisis. For instance, in response to a negative shock which requires a real depreciation, domestic inflation must fall, leading to a procyclical markup.

The tables show in addition that the lack of nominal exchange rate variation and the procyclicality of the markup lead to much greater volatility of consumption, output and employment under the peg than under either flexible exchange rate regime, when the country is in a crisis. In crisis times, the standard deviation of output under the peg is well over twice that in the floating regimes. In addition, the volatility of the price markup itself is dramatically higher under the peg.

These findings illustrate that the analysis of 'sudden stop' financial crises in emerging markets based on financial frictions has to carefully take account of the monetary policy stance being followed by each country. In all cases, 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 significantly affected by the exchange rate regime. Under a pegged exchange rate, when a crisis hits, it has a much more damaging effect.

We can also illustrate the benefits of departing from a strict inflation targeting monetary policy to an optimal discretionary monetary policy during a crisis. From table 3 we see that an optimal monetary response to a crisis generates a countercyclical markup, leading to a higher rate of inflation. As a result, output and employment volatility during a crisis are reduced, when compared with the policy of strict inflation targeting. But this benefit is slight. Quantitatively, the difference between the strict inflation targeting regime and the optimal monetary policy is negligible.[6]

Tables 2, 3 and 4 also provide information on the frequency of crises across each regime. Given the inequality condition represented in (6), the frequency with which this constraint binds is determined by a complicated combination of variables and the interaction between them, including the price of capital, the real exchange rate, the level of external debt, and the realization of the shocks to productivity, the leverage parameter, and the foreign interest rate.

The tables indicate that under the inflation targeting regime, the crisis frequency is 11 percent. Optimal monetary policy reduces this slightly to 10.7%. But under the exchange rate peg, the crisis frequency is significantly lower, at 6.8%. At first glance, this is a curious implication of the model, since as we have discussed, the peg reduces the economy's ability to respond to negative shocks. Upon a further decomposition of shocks in the model (as shown in the Appendix) we find that the source of this differential in crisis frequency is tied to the presence of productivity shocks. Under the exchange rate peg, the real price of capital (i.e. $\frac{q_{t+1}}{e_{t+1}}$) is much less responsive to a persistent productivity shock than under either flexible exchange rate arrangement. A productivity shock which leads to an expected fall in the real price of capital and a binding collateral constraint in a flexible exchange rate system is less likely to push the economy into a binding constraint under the peg.[7] Despite this, however, once the constraint does bind, the outcome under the peg is

[6] This result would be qualified were we to introduce nominal wage stickiness in addition to price stickiness in the model. See Devereux, Young and Yu (2015).

[7] As the Appendix shows, if the model is driven only by foreign interest rate shocks and leverage shocks, the frequency of crises is the same under all exchange rate arrangements.

significantly worse, as we have shown above.

The latter conclusion is supported by the conditional welfare evaluation reported in the Tables. The results indicate that conditional welfare is essentially equivalent in the strict inflation targeting regime and the optimal monetary policy regime.[8] But both dominate conditional welfare under a peg, even though the frequency of crises under a peg is less than that in the floating exchange rate regimes.

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 1 and 2 report variables of interest during the evolution of a crisis. When a crisis occurs unexpectedly, the borrowing constraint becomes tighter, leading to a sudden jump in the Lagrange multiplier μ. Imports, output, employment and consumption decline dramatically. But clearly, the response under a peg is substantially greater in most dimensions. The multiplier jumps much more under the peg. The fall in borrowing is much greater, and the impact on the real economy (the fall in output, imports, employment and consumption) is significantly greater. At the same time, 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 Figures also illustrate that on average, a crisis under a pegged exchange rate regime is precipitated at a lower level of net external debt than under the floating regime. As we described above, on average the exchange rate peg leads to a lower mean level of external borrowing due to precautionary saving motives.

Finally, the Figures also establish that while an optimal monetary policy differs from the strict

[8]This is not exactly true. As to be expected, the optimal monetary policy regime will raise conditional welfare through the more accommodative policy during a crisis. But the effect is negligible up the to accuracy calculated by our solution.

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, 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 macro-prudential policy.

5.2 Empirical Implications

Empirically, there is some evidence that the frequency of crises is lower under pegged exchange rates, although the exact definition of a crisis becomes an important factor. It can be argued that our model is more specifically descriptive of banking crises, since a binding collateral constraint directly affects the use of borrowed funds to finance production and inter-temporal consumption smoothing. 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. Interestingly, Domac and Martinez Peria (2003) also find that once a banking crisis occurs, the real costs of the crisis seem to be higher in countries with fixed exchange rate regimes. This also accords with the findings of our model. The evidence on currency crises and exchange rate pegs is more mixed. In an important early contribution, Obstfeld and Rogoff (1995) make a very clear case for the risk of currency crises inherent in pegged exchange rate regimes with open capital markets. They point to risks associated with accumulated overvaluation as a result of domestic policy that becomes increasingly inconsistent with the maintenance of an exchange rate peg (citing the example of the Mexican 1995 crisis in particular). While our model is focused on the importance of financial frictions, we are assuming in the background that the exchange rate peg is itself sustainable, so we do not incorporate these difficulties associated with the possible collapse of the exchange rate regime due to unsustainable fiscal trajectories, or political economy considerations.

More recent evidence on the relationship between the exchange rate regime and crises is offered in Ghosh, Ostry and Qureshi (2015). Based on a more recent sample of data for 50 emerging market economies over 1980-2011, they show that narrow-defined peg regimes are associated with lower banking and currency crisis than other exchange rate regimes. They show in fact that there is a non-monotonic relationship between crises frequency and the degree of exchange rate flexibility in their sample. Again, this is broadly in line with the implications of our model.

Table 2: Model moments under the strict inflation targeting regime

	Mean	Std.(%)	Corr(.,GDP)
Probability of crisis	11.1		
Conditional welfare ($b_t^* = -0.35$, $e_{t-1} = 1$)	0.38848		
Panel A: the whole sample			
Effective consumption	0.3883	1.14	0.81
Output	0.6877	1.80	1.00
Bond	-0.3185	1.31	0.23
Real exchange rate	0.9871	0.69	0.53
Price markup	1.0000	0.00	0.00
Inflation	1.0000	0.00	0.00
Labor	0.9898	1.30	1.00
Capital price	0.9364	3.43	0.84
Domestic interest rate	1.0254	5.76	-0.32
External finance premium	0.0074	3.91	-0.30
Panel B: the subsample with binding constraints			
Effective consumption	0.3677	2.10	0.78
Output	0.6645	1.82	1.00
Bond	-0.3064	2.83	-0.03
Real exchange rate	0.9904	1.14	-0.22
Price markup	1.0000	0.00	0.00
Inflation	1.0000	0.00	0.00
Labor	0.9730	1.33	1.00
Capital price	0.8738	5.70	0.81
Domestic interest rate	1.1042	15.29	-0.57
External finance premium	0.0665	10.08	-0.53

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 under optimal monetary policy

	Mean	Std.(%)	Corr(.,GDP)
Probability of crisis	10.7		
Conditional welfare ($b_t^* = -0.35$, $e_{t-1} = 1$)	0.38848		
Panel A: the whole sample			
Effective consumption	0.3883	1.14	0.80
Output	0.6877	1.79	1.00
Bond	-0.3183	1.31	0.24
Real exchange rate	0.9871	0.70	0.53
Price markup	1.0001	0.08	-0.28
Inflation	1.0000	0.01	-0.27
Labor	0.9899	1.28	1.00
Capital price	0.9364	3.42	0.84
Domestic interest rate	1.0254	5.77	-0.30
External finance premium	0.0074	3.92	-0.28
Panel B: the subsample with binding constraints			
Effective consumption	0.3676	2.14	0.75
Output	0.6652	1.79	1.00
Bond	-0.3047	2.80	-0.02
Real exchange rate	0.9908	1.18	-0.18
Price markup	1.0014	0.21	-0.51
Inflation	1.0002	0.03	-0.52
Labor	0.9742	1.26	1.00
Capital price	0.8734	5.79	0.78
Domestic interest rate	1.1072	15.56	-0.54
External finance premium	0.0690	10.23	-0.50

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 4: Model moments under the pegged regime

	Mean	Std.(%)	Corr(.,GDP)
Probability of crisis	6.8		
Conditional welfare ($b_t^* = -0.35$, $e_{t-1} = 1$)	0.38794		
Panel A: the whole sample			
Effective consumption	0.3879	1.02	0.97
Output	0.6877	1.65	1.00
Bond	-0.3163	0.80	-0.05
Real exchange rate	0.9874	0.30	-0.01
Price markup	1.0005	2.41	0.56
Inflation	1.0000	0.30	0.41
Labor	0.9900	2.10	0.88
Capital price	0.9338	3.05	0.97
Domestic interest rate	1.0252	5.89	-0.82
External finance premium	0.0073	3.58	-0.82
Panel B: the subsample with binding constraints			
Effective consumption	0.3634	2.77	0.99
Output	0.6492	4.49	1.00
Bond	-0.2770	0.61	0.24
Real exchange rate	0.9886	0.52	-0.47
Price markup	0.9676	6.07	0.91
Inflation	0.9993	0.60	0.81
Labor	0.9460	6.09	0.98
Capital price	0.8602	7.72	0.99
Domestic interest rate	1.1654	18.68	-0.96
External finance premium	0.1070	10.60	-0.97

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.

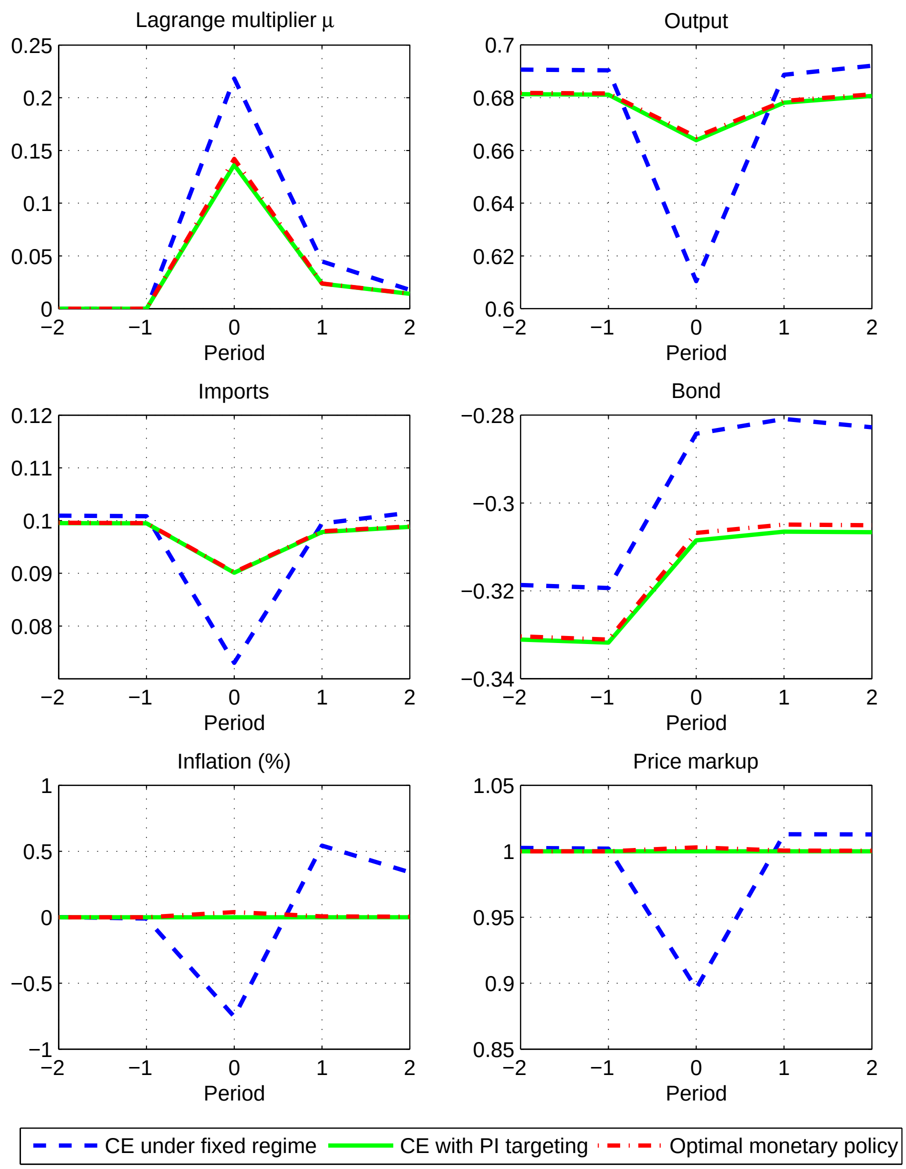

Figure 1: Event analysis for the competitive equilibrium under the strict price inflation targeting regime, optimal monetary policy under the floating and a pegged exchange rate regime. A typical five-period event window is chosen as: (a) no binding collateral constraints in the first two periods $t = -2, -1$, (b) binding constraint at period $t = 0$ and (c) no restrictions in the last two periods $t = 1, 2$. The events in the figure are an average of all event series in a simulation of $200,000$ periods.

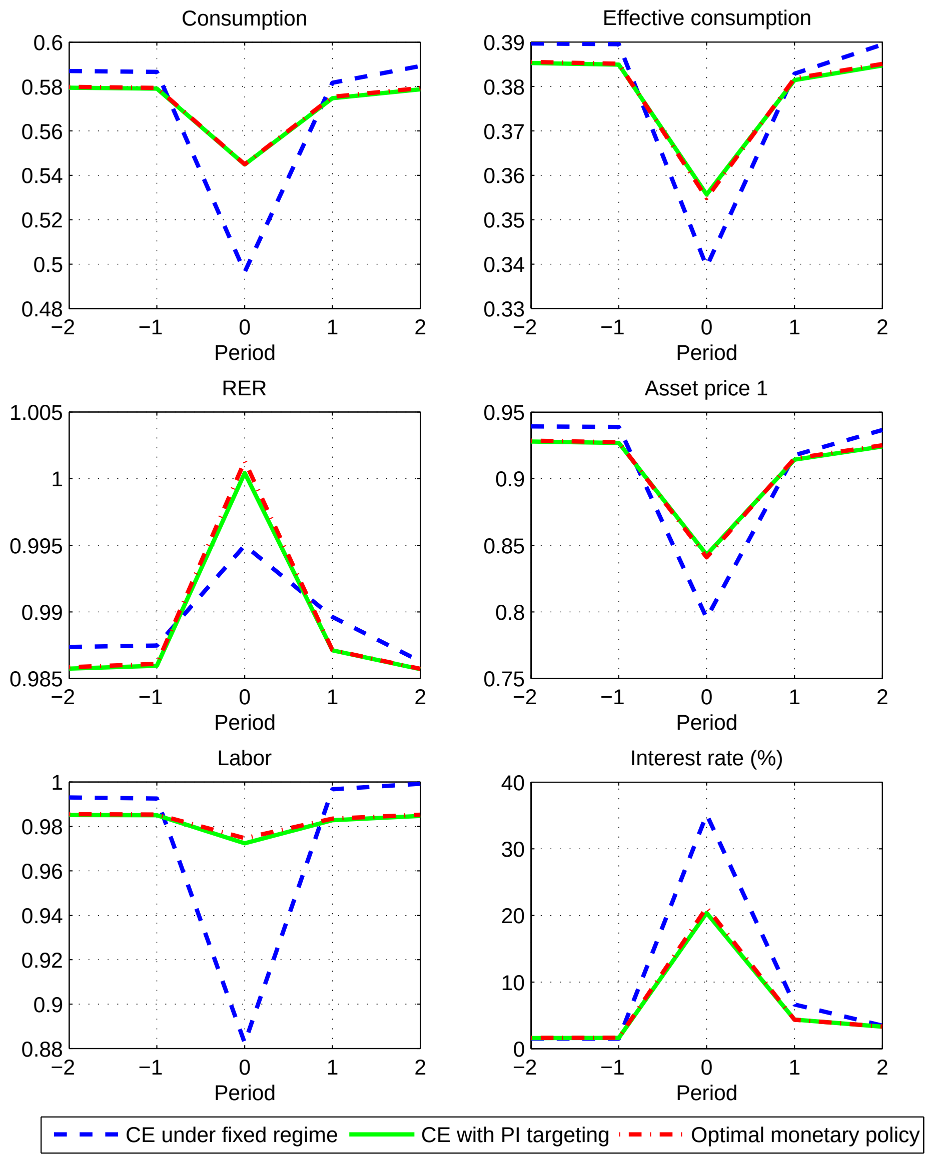

Figure 2: Event analysis for the competitive equilibrium under the strict price inflation targeting regime, optimal monetary policy under the floating and a pegged exchange rate regime. A typical five-period event window is chosen as: (a) no binding collateral constraints in the first two periods $t = -2, -1$, (b) binding constraint at period $t = 0$ and (c) no restrictions in the last two periods $t = 1, 2$. The events in the figure are an average of all event series in a simulation of $200,000$ periods.

6 Capital Controls and Exchange Rate Policy

In the baseline model, we have two types of frictions: nominal rigidities and pecuniary externalities. In both cases, depending on the details of the model, there may be a welfare case for government intervention in international capital markets. With sticky prices, Farhi and Werning (2012, 2013) show that capital controls may be welfare improving when an economy has an existing precommitment to an exchange rate peg.[9] Alternatively, when collateral constraints depend on relative prices, Bianchi (2011), Bianchi and Mendoza (2010), Jeanne and Korinek (2010), and Benigno, Chen, Otrok, Rebucci and Young (2013) show that there will in general arise pecuniary externalities that may be offset by optimally designed taxes or subsidies.

Our setup combines both sticky prices and pecuniary externalities associated with the endogenous price of capital in the collateral constraint. In principle therefore, both of the above arguments for intervention in capital markets may be supported. However, under a regime of flexible exchange rates, the monetary authority effectively supports the flexible price equilibrium, so the only reason for a capital market intervention is to offset the pecuniary externality. By contrast, with an exchange rate peg, the presence of nominal rigidities and the pecuniary externality are jointly present as market failures that may require offsetting capital taxes or subsidies.

It follows that when the borrowing capacity is exogenously given, so that there is no pecuniary externality associated with the effect of the capital price on the borrowing limit, there is no benefit of a capital inflow tax or subsidy under the floating regime. This is because the floating regime can replicate the full flexible price equilibrium and there is no further gain from driving a wedge between the domestic and world interest rate. But with a collateral constraint in the form of (6), the pecuniary externality will in general imply the need for an additional policy instrument, and in particular we can focus a capital tax as the instrument.

In Devereux, Young and Yu (2015) it is shown that a capital inflow *subsidy* can raise expected utility for households in the small economy when the central bank follows an optimal monetary

[9] Schmitt-Grohe and Uribe (2013) establish a similar result in the case of downward wage rigidity.

policy (under floating exchange rates).[10] This is because the subsidy boosts the demand for capital, raising the capital price in times of crisis, and acts so as to relax the collateral constraint.

More generally, there will be a trade-off between the benefits of capital inflow taxes and capital inflow subsidies. Households are impatient relative to the rest of the world. Ceteris paribus, they would like to borrow more and front load their consumption. On the one hand, subsidizing capital inflows encourages households to borrow more. A rise in borrowing increase households' consumption and pushes up the capital price, which in turn further relaxes the borrowing constraint. In other words, there are *positive* externalities in the market for collateral capital. Policy makers take into account these positive externalities and will, ceteris paribus, allow households and firms to borrow more.[11]

On the other hand, higher borrowing and leverage will raise the probability (panel A of figure 3) and more importantly the severity of a financial crisis. Whether welfare improves or not under capital controls, and whether the policy maker should tax or subsidize capital inflows depends on the tradeoff between the positive pecuniary externalities and higher costs of a financial crisis.

Under the floating regime, once monetary policy stabilizes domestic inflation, a constant capital inflow subsidy will increase borrowing capacity and welfare for the reason we have discussed above. By contrast, in the pegged exchange rate regime, a capital inflow subsidy produces a larger distortion, since both prices and the nominal exchange rate are sticky. As we have seen in the previous section, with similar levels of external debt, a crisis has significantly worse outcomes under a pegged exchange rate. A capital subsidy increases the average level of external debt, leading to a higher external finance premium and higher nominal interest rates during the crisis, as shown in figure 5.

Panel B of figure 3 and panel A of figure 4 show the relation between welfare change and the

[10] This policy will in general be time inconsistent, in the absence of a commitment technology. As shown in Devereux, Young and Yu (2015), the time consistent policy is to impose a capital tax during a crisis, and in equilibrium, this will lead to lower welfare than in the absence of a tax.

[11] In evaluating the benefits of capital subsidies, it is important to use a conditional welfare measure. As described in the Appendix, conditional welfare incorporates the transitional benefits to domestic households from being able to front load consumption, given that their rate of time preference exceeds the world interest rate. The impact of the policy on the unconditional welfare measure is likely to be quite different. Since a capital subsidy shifts out the stationary distribution of debt in the economy, in general a subsidy will tend to reduce unconditional welfare, as we show below.

sign and size of capital inflow taxes for the cases of strict inflation targeting, optimal monetary policy, and the pegged exchange rate regime. We find that in all cases, a small time invariant capital subsidy can increase welfare, as it enhances the economy's borrowing capacity. But the welfare benefits of a subsidy under the peg are substantially lower than those under either of the flexible exchange rate arrangements. We find that the optimal subsidy under a peg is very small - at around 1 percent. For the floating exchange rate regimes, welfare continues to increase for much higher rates of subsidy.[12]

In summary, we find that under a flexible exchange rate, a capital inflow subsidy can significantly increase welfare by enlarging borrowing capacity. But under a pegged exchange rate regime, the welfare gains are significantly offset by the increased nominal distortions implied by higher levels of external debt.

Panel B of figure 4 shows the importance of distinguishing conditional from unconditional welfare. The panel shows the relationship between the capital inflow tax and subsidy and unconditional welfare (measured by permanent change of effective consumption) across exchange rate regimes. By increasing the stationary distribution of debt, a capital inflow subsidy reduces unconditional welfare under all exchange rate arrangements. But welfare declines more rapidly for the pegged regime than the floating regime when the capital inflow subsidy increases, and welfare rises more quickly for the pegged regime as the capital inflow tax increases.

Note that we choose capital controls arbitrarily, and optimal monetary policy should take into account the presence of these capital controls. Figure 5 and 6 shows that the price markup (and therefore the average inflation rate) is systematically related to the capital inflow tax/subsidy. During normal times, the inflation rate decreases as the subsidy rises, while during crises, the opposite relationship holds. This result is consistent with Farhi and Werning (2012) and Farhi and Werning (2013), who show that capital inflow tax can reduce inflation dynamics and the adjustment of relative prices.

[12]Conditional welfare reaches a maximum as we increase the subsidy rate under the floating exchange rate regime, but our solution method becomes less accurate, since we need to expand the domain progressively as the subsidy is increased.

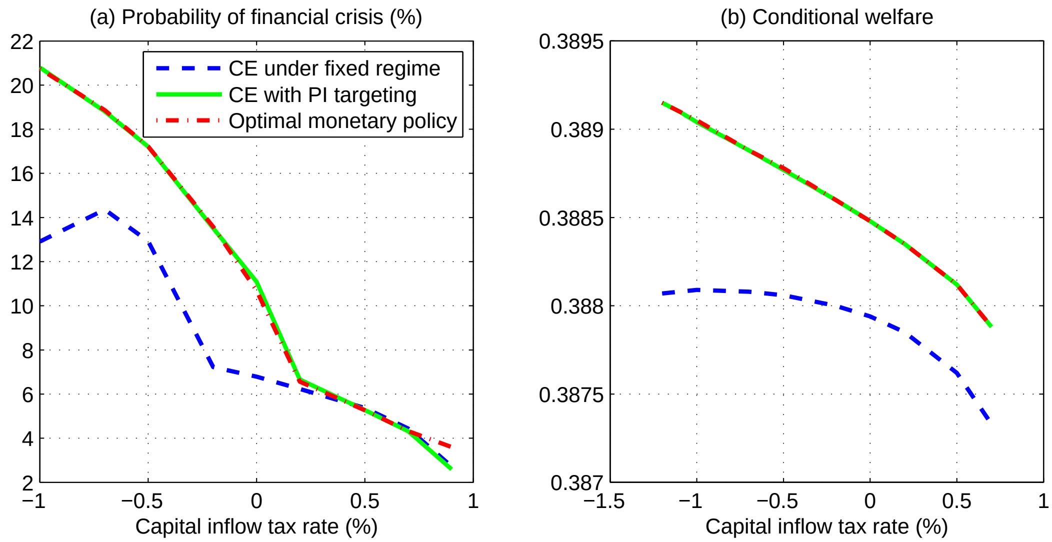

Figure 3: The unconditional probability of financial crisis (panel a) and conditional welfare gains (panel b) relative to no capital control for the competitive equilibrium under the strict price inflation targeting regime, optimal monetary policy under the floating and a pegged exchange rate regime. The initial conditional for welfare is $b_t^* = -0.35$, $e_{t-1} = 1$. Welfare gains and losses are lower for lower external borrowing.

Based on the analysis above, we conjecture that a capital inflow subsidy/tax either in crises or in normal times may have similar effects as a constant capital flow regulation. As a robustness check, we link the capital control with the tightness of the borrowing constraint (6). Results (not reported here) confirm that capital inflow subsidy quantitatively makes domestic agents better off under both exchange rate regimes, but they gain much more under the floating regime. Monetary policy will work with capital control regulation jointly to stabilize the domestic economy.

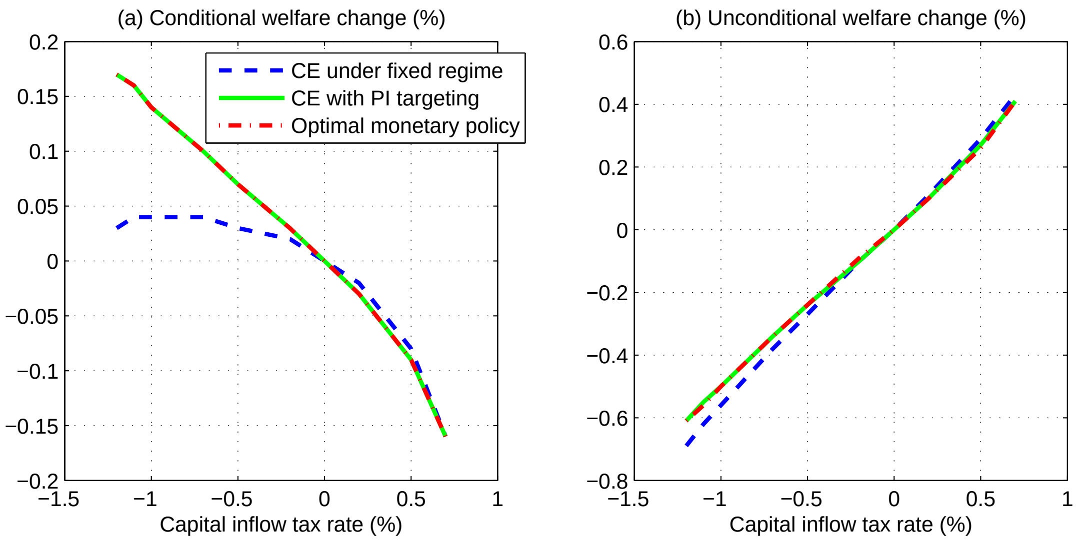

Figure 4: Conditional welfare change (panel a) and unconditional welfare change (panel b) relative to the case without capital controls for the competitive equilibrium under the strict price inflation targeting regime, optimal monetary policy under the floating and a pegged exchange rate regime. The initial conditional for welfare is $b_t^* = -0.35$, $e_{t-1} = 1$.

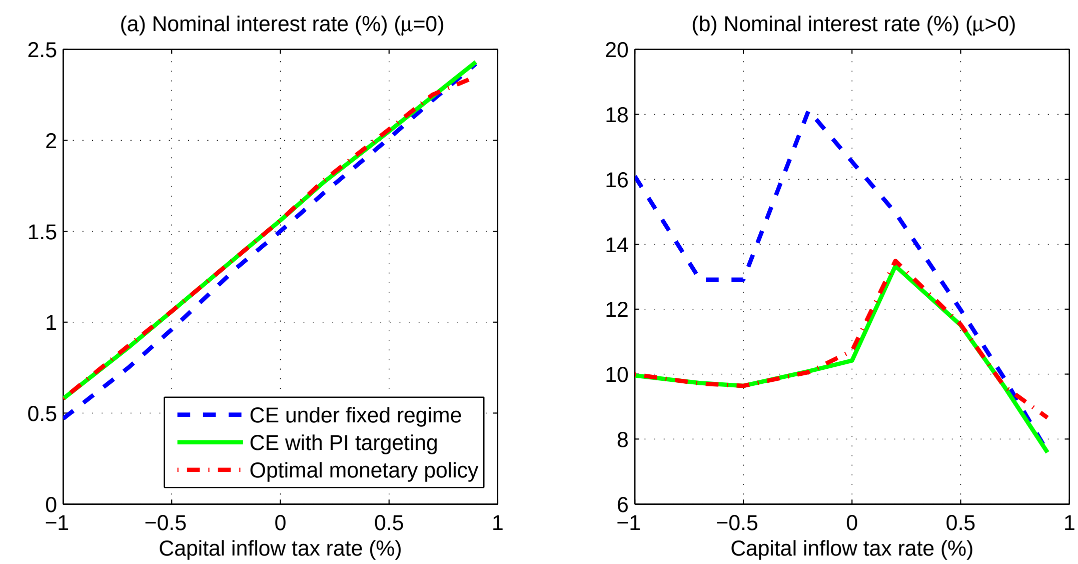

Figure 5: Average domestic nominal interest rates for the competitive equilibrium under the strict price inflation targeting regime, optimal monetary policy under the floating and a pegged exchange rate regime. The initial conditional for welfare is $b_t^* = -0.35$, $e_{t-1} = 1$.

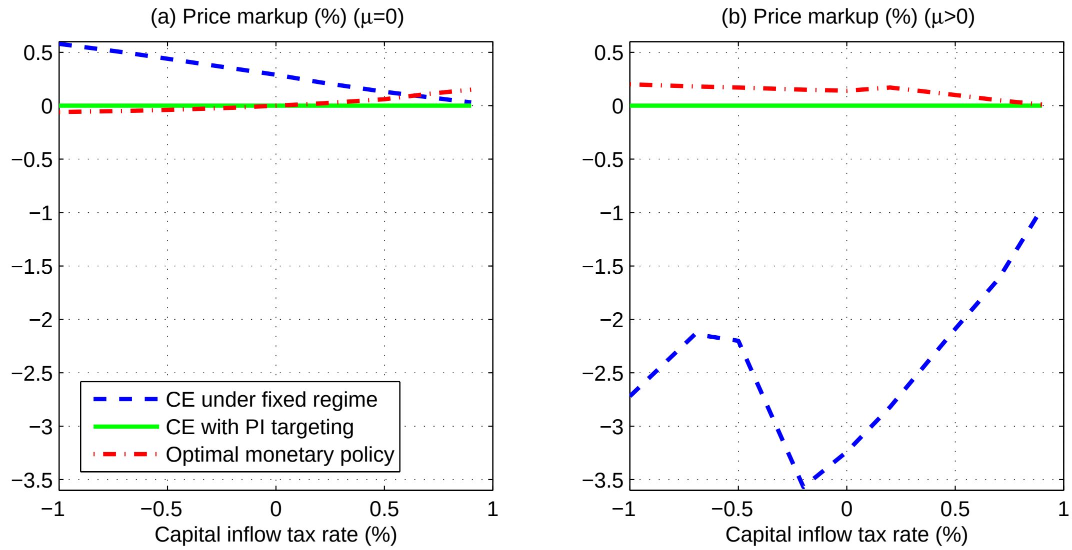

Figure 6: Average price markups $p_{M,t} - 1$ for the competitive equilibrium under the strict price inflation targeting regime, optimal monetary policy under the floating and a pegged exchange rate regime. The initial conditional for welfare is $b_t^* = -0.35$, $e_{t-1} = 1$.

7 Conclusion

This paper has compared the positive and normative affects of alternative monetary and exchange rate policies in a model of a small open economy which is subject to occasional 'sudden stops' associated with binding borrowing constraints. Borrowing constraints in the model depend on endogenous movements in asset prices. The paper represents an extension of the growing literature on sudden stops in emerging economies to environments where there exist nominal rigidities and as a result the exchange rate stance represents an important factor in analyzing the response to crises. We find that in normal times, when the economy is away from the constrained states, there is little difference between alternative exchange rate policies. But during a crisis, macro outcomes are far worse under a pegged exchange rate. The model also gives predictions about the frequency of crises. We find that under some shock configurations, crises may be less frequent under a pegged exchange rate regime. Despite this, the worse performance during a crisis leads the pegged exchange rate regime to be inferior to both types of floating regimes. Finally, we show that in the presence of pecuniary externalities in asset prices, there may be a case for a fiscal authority to subsidize capital inflows at a constant rate. But the benefits of capital inflow subsidies are much weaker under pegged exchange rates.

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Not for Publication Appendices

A Model moments without productivity shocks

Table A-1: Model moments under the strict inflation targeting regime

	Mean	Std.(%)	Corr(.,GDP)
Probability of crisis	9.9		
Conditional welfare ($b_t^* = -0.35$, $e_{t-1} = 1$)	0.38739		
Panel A: the whole sample			
Effective consumption	0.3883	0.82	0.98
Output	0.6878	0.43	1.00
Bond	-0.3251	1.06	-0.42
Real exchange rate	0.9874	0.45	-0.94
Price markup	1.0000	0.00	0.00
Inflation	1.0000	0.00	0.00
Labor	0.9900	0.31	1.00
Capital price	0.9392	2.39	0.96
Domestic interest rate	1.0256	4.98	-0.99
External finance premium	0.0079	3.81	-1.00
Panel B: the subsample with binding constraints			
Effective consumption	0.3767	2.10	1.00
Output	0.6802	1.10	1.00
Bond	-0.2816	0.20	0.91
Real exchange rate	0.9925	1.11	-1.00
Price markup	1.0000	0.00	0.00
Inflation	1.0000	0.00	0.00
Labor	0.9845	0.80	1.00
Capital price	0.9034	5.85	1.00
Domestic interest rate	1.1115	13.14	-1.00
External finance premium	0.0795	9.78	-1.00

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 A-2: Model moments under optimal monetary policy

	Mean	Std.(%)	Corr(.,GDP)
Probability of crisis	9.9		
Conditional welfare ($b_t^* = -0.35$, $e_{t-1} = 1$)	0.38739		
Panel A: the whole sample			
Effective consumption	0.3883	0.82	0.98
Output	0.6879	0.39	1.00
Bond	-0.3249	1.06	-0.41
Real exchange rate	0.9874	0.46	-0.95
Price markup	1.0001	0.08	-0.99
Inflation	1.0000	0.01	-0.99
Labor	0.9902	0.24	1.00
Capital price	0.9393	2.39	0.96
Domestic interest rate	1.0256	4.99	-0.99
External finance premium	0.0079	3.82	-1.00
Panel B: the subsample with binding constraints			
Effective consumption	0.3768	2.10	1.00
Output	0.6811	0.99	1.00
Bond	-0.2815	0.19	0.90
Real exchange rate	0.9927	1.14	-1.00
Price markup	1.0018	0.21	-1.00
Inflation	1.0002	0.03	-1.00
Labor	0.9860	0.62	1.00
Capital price	0.9037	5.84	1.00
Domestic interest rate	1.1115	13.17	-1.00
External finance premium	0.0795	9.81	-1.00

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 A-3: Model moments under the pegged regime

	Mean	Std.(%)	Corr(.,GDP)
Probability of crisis	9.9		
Conditional welfare ($b_t^* = -0.35$, $e_{t-1} = 1$)	0.38704		
Panel A: the whole sample			
Effective consumption	0.3881	0.82	0.99
Output	0.6881	1.33	1.00
Bond	-0.3243	0.69	-0.36
Real exchange rate	0.9876	0.17	-0.84
Price markup	1.0005	1.87	0.99
Inflation	1.0000	0.19	0.87
Labor	0.9905	1.88	1.00
Capital price	0.9376	2.45	0.98
Domestic interest rate	1.0254	4.84	-0.97
External finance premium	0.0080	3.40	-0.95
Panel B: the subsample with binding constraints			
Effective consumption	0.3751	2.08	0.99
Output	0.6672	3.41	1.00
Bond	-0.2822	0.32	0.97
Real exchange rate	0.9892	0.39	-0.86
Price markup	0.9749	4.81	1.00
Inflation	0.9996	0.49	0.95
Labor	0.9627	4.83	1.00
Capital price	0.8976	5.99	0.99
Domestic interest rate	1.1197	12.43	-0.99
External finance premium	0.0804	8.48	-0.98

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.

B 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

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

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

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

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.