Financial Crises, Monetary Policy and Exchange Rate Dynamics

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1 Introduction

This paper studies the optimal and time-consistent use of monetary policy to combat Sudden Stops. Following the now-substantial literature on pecuniary externalities, we use a model in which collateral constraints bind occasionally, and when they bind they set off large capital outflows (the so-called Fisherian deflation or financial accelerator effect). These outflows in turn generate substantial recessions in the domestic economy, and are inefficient in general.

We extend the existing literature by studying monetary policy, rather than fiscal policy, and using a model with nominal rigidities. Such a model opens a number of interesting questions, including (i) is there a tradeoff between managing the problem of sticky prices and managing the pecuniary externality when the number of instruments is limited?; (ii) if there is a tradeoff, what parameters govern how this tradeoff is resolved?; and (iii) should the monetary authority be given additional tools, such as capital controls?

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We study the equilibrium of a model with sticky prices and a collateral constraint – foreign borrowing is limited to a fraction of the value of domestic capital (which is in fixed supply). We then characterize the three inefficiencies in the model – nominal rigidities, market power, and the pecuniary externality driven by the collateral constraint.

1.1 Related literature

This paper is related to several strands of recent literature.

1.1.1 Overborrowing and macroprudential policy

Bianchi (2011) studied an endowment economy with tradable and nontradable sectors. As private agents do not internalize the effects of their borrowing on asset prices the economy generally features overborrowing; specifically, during a financial crisis the collateral constraint binds, which reduces the value of collateral further, leading to an even tighter constraint. The result is a "Sudden Stop" and a sharp deep recession. Bianchi and Mendoza (2010) show that state-contingent capital inflow taxes will prevent overborrowing, which can be interpreted as a form Pigouvian taxation (Jeanne and Korinek 2010). Schmitt-Grohe and Uribe (2014) explore a model with downward wage rigidity to explain the large recession in the Euro zone. When there exist ex post adjustments of production between tradable and nontradable sectors, private agents could exhibit underborrowing (Benigno et al. 2013). Korinek (2011) provides a comprehensive review on borrowing and macroprudential policies during financial crises. As for optimal policy, Bianchi and Mendoza (2013) and Benigno et al. (2012,2015) explore time-consistent macroprudential policy.

1.1.2 Monetary policy and capital controls in a SOE

The classical Mundell-Fleming model has been the workhorse model guiding policy analysis over past several decades. The recent financial crisis requires a further understanding of capital flows and financial stability across borders. Rey (2013) showed that volatile capital flows could hurt an economy even under flexible exchange rate regime and commented that a dilemma rather than a trilemma exists in the real world economy. Several recent works follow this line of research. Farhi and Werning (2012) and Farhi and Werning (2013) investigated optimal capital controls and monetary policy in a Gali-Monacelli type of small open economy model (Gali and Monacelli 2008) and showed that capital controls help regain monetary autonomy in a fixed exchange rate regime and work as terms of trade manipulation in a flexible exchange rate regime. Capital controls as terms of trade manipulation were first explored by Costinot, Lorenzoni, and Werning (2014) in a two-country deterministic endowment economy.

Some other authors focus on exchange rate policies. Fornaro (2014) extended Bianchi (2011) to an infinite number of small open economies and explored how debt deleveraging produces a world-wide recession in a monetary union. In a similar model, Fornaro (2015) investigated the tradeoff between price and financial stability in a SOE with sticky wages and credit constraints and explored exchange rate policies of Taylor rule. Liu and Speigel (2013) examine monetary policy and capital account regulation in a small open economy. Faia and Iliopulos (2011) show that the optimal monetary policy aims to stabilize the exchange rate and domestic inflation. Schmitt-Grohe and Uribe (2014) explore downward wage rigidity and involuntary employment for a small open economy with fixed exchange rates.

Our paper seems to be the first that nontrivial exchange rate determination with nominal rigidities and asset price-based collateral mechanisms.

1.1.3 Aggregate demand externality

Korinek and Simsek (2015) study an aggregate demand externality at the ZLB, wherein the inability of the nominal interest rate to drop below zero when needed to stimulate consumption creates a positive role for macroprudential policy. Since their paper is in a closed-economy setting the particular policies they advocate are quite different from ones that would arise in our model. In any case, our economy does not encounter the ZLB given a reasonable inflation target, so we can safely abstract from the issues they raise.

2 The model

We consider a monetary version of a small open economy akin to Mendoza (2010). There exist infinitely lived firm-households with unit measure. Competitive domestic firms import intermediate inputs and hire domestic labor and physical capital to produce wholesale goods. These wholesale goods are differentiated into various varieties by domestic monopolistically competitive final goods producers, which are then aggregated by competitive bundlers into consumption composites. These composites either are consumed by domestic households or exported to the rest of the world. International financial markets are incomplete. Domestic households only trade foreign currency denominated, say dollar, non-state-contingent bonds with foreigners. If the net foreign asset position is negative, that debt must satisfy a collateral requirement.

Whole sale good production takes a form of Cobb-Douglas production

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

with $\alpha_F + \alpha_L + \alpha_K \leq 1$. M_t denotes the production of the wholesale good, A_t a country-wide exogenous technological shock, $Y_{F,t}$ imported intermediate inputs, L_t labor demand, and K_t physical capital. Imported intermediate inputs are an aggregate of different varieties:

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

where θ represents the elasticity of substitution between imported varieties. The dollar price of variety i is denoted by $P^*_{F,t}(i)$. A variable with script $*$ on its shoulder denotes a foreign variable. Let $\mathcal{E}_t$ be the nominal exchange rate, which measures the price of foreign currency in terms of domestic currency. Assume that the Law of One Price holds for each variety. Cost minimization implies that the price of imported intermediate inputs $Y_{F,t}$ is given by

$$P_{F,t} = \left(\int_0^1 \left(P^*_{F,t}(i) \right)^{1-\theta} di \right)^{\frac{1}{1-\theta}} \mathcal{E}_t. \tag{3}$$

Suppose that prices in the rest of world are exogenously given. For simplicity but without loss of generality, we assume prices of intermediate varieties remain the same $P^*_{F,t} = P^*_{F,t}(i)$ in the rest of world. Foreign demand for domestic consumption composites, X_t, is given by

$$X_t = \left(\frac{P_t}{\mathcal{E}_t P^*_t} \right)^{-\rho} \zeta^*_t, \tag{4}$$

ζ^*_t stands for a foreign demand shock and describes foreign consumption expenditure shocks. $\rho > 1$ is the elasticity of substitution between imports and locally produced goods in a foreign consumption basket.[1] The share of expenditures in the foreign country (the rest of world) on imports from a small country remains ignorable. Therefore, CPI index in the foreign country can be written as $P^*_t = P^*_{F,t}(i) = 1$, where the foreign price is normalized to 1.

2.1 Firm-households

A representative firm-household has preferences given by

$$E_0 \left[\sum_{t=0}^{\infty} \beta^t U \left(c_{t,t} \right) \right], \tag{5}$$

where E_0 stands for the mathematical expectation conditional on information up to date 0. We assume that the subjective discount factor is constrained by $\beta R^*_{t+1} < 1$ to capture the fact that firm-households are net borrowers at the deterministic steady state. R^*_{t+1} denotes foreign real interest rate. Period utility function takes the GHH (Greenwood, Hercowitz, and Huffman 1988) form

$$U(c_t, l_t) = \frac{\left(c_t - \chi \frac{l_t^{1+\nu}}{1+\nu} \right)^{1-\gamma} - 1}{1-\gamma}. \tag{6}$$

Similar to Mendoza (2010), households can borrow from abroad to finance consumption and imported intermediate inputs. Assume that borrowing is denominated in foreign currency; in addition

[1]This foreign demand function can be derived from a world economy as in Gali and Monacelli (2008). ρ measures the elasticity of substitution among varieties produced in the world.

borrowing from abroad requires physical capital k_{t+1} as collateral,

$$\vartheta Y_{F,t} P^*_{F,t} - B^*_{t+1} \leq \kappa_t E_t \left\{ \frac{Q_{t+1} k_{t+1}}{\mathcal{E}_{t+1}} \right\}, \tag{7}$$

B^*_{t+1} is domestic savings in dollars at the end of period t, ϑ measures the fraction of imported inputs $Y_{F,t}$ which must be financed in advance, and Q_{t+1} denotes the nominal capital price. Parameter κ_t characterizes the loan-to-value ratio in the spirit of Kiyotaki and Moore (1997).[2]

Firm-households own all of domestic firms equally and consequently they make the same consumption and borrowing decisions. We write the decisions for the wholesale good producer explicitly. Demand and supply decisions on other factors and products can be obtained by maximizing a representative firm's profits in the corresponding competitive factor and product markets, which are omitted in the firm-household's budget constraint. A representative firm-household faces the budget constraint

$$P_t c_t + Q_t k_{t+1} + \frac{B_{t+1}}{R_{t+1}} + \frac{B^*_{t+1}\mathcal{E}_t}{R^*_{t+1}} \leq W_t l_t + k_t(R_{K,t} + Q_t) + B_t + B^*_t \mathcal{E}_t + T_t + \big[P_{M,t} M(Y_{F,t}, L_t, K_t) - Y_{F,t} P^*_{F,t}\mathcal{E}_t - W_t L_t \tag{8}$$

The left-hand side of the equation above displays consumption expenditure $P_t c_t$, purchases of capital $Q_t k_{t+1}$, savings denominated in domestic currency B_{t+1}/R_{t+1} and in dollars $B^*_{t+1}\mathcal{E}_t/R^*_{t+1}$. The right-hand side shows the various income sources for the household, including labor income $W_t l_t$, gross returns on capital $k_t(R_{K,t} + Q_t)$, gross returns on domestic savings B_t and foreign savings $B^*_t \mathcal{E}_t$, lump-sum transfers from government T_t, profits from whole sale good producers $P_{M,t} M_t - Y_{F,t}\mathcal{E}_t - W_t L_t - R_{K,t} K_t$ and profits from other firms D_t. The wholesale good production M_t is given by equation (1). We assume that working capital incurs no interest rate payments as in Bianchi and Mendoza (2013).

Let $\mu_t e_t$ be the Lagrange multiplier for collateral constraint (7). Let a lower case price variable

[2]Note that we could use an alternative form of collateral constraints, such as $\vartheta Y_{F,t} P^*_{F,t} - B^*_{t+1}/R^*_{t+1} \leq \kappa_t Q_t k_{t+1}/\mathcal{E}_t$. However, given others unchanged, pecuniary externality doesn't cause inefficiency here since current borrowing won't affect future prices at all. The specification in equation (7) can separate the impacts of terms of trade manipulation and pecuniary externality.

denote the real price, i.e., $q_t = Q_t/P_t$, $w_t = W_t/P_t$. Consumer price index inflation is defined as $\pi_t = P_t/P_{t-1}$ and the real exchange rate is $e_t = \mathcal{E}_t P_t^*/P_t$, so that higher e_t implies a depreciation of the real exchange rate. The optimality condition for labor supply is

$$w_t = \chi l_t^\nu. \tag{9}$$

Optimality conditions for portfolio yield

$$q_t = \mu_t \kappa_t E_t \left\{ \frac{q_{t+1} e_t}{e_{t+1}} \right\} + E_t \left\{ \beta \frac{U_c(t+1)}{U_c(t)} (r_{K,t+1} + q_{t+1}) \right\}, \tag{10}$$

$$1 = E_t \left\{ \beta \frac{U_c(t+1)}{U_c(t)} \frac{R_{t+1}}{\pi_{t+1}} \right\}, \tag{11}$$

$$1 = \mu_t R_{t+1}^* + E_t \left\{ \beta \frac{U_c(t+1)}{U_c(t)} \frac{e_{t+1}}{e_t} R_{t+1}^* \right\}, \tag{12}$$

where $U_c(t)$ denotes the marginal utility of consumption.

The optimal demand for intermediate inputs for a wholesale producer satisfy

$$p_{M,t} \frac{\alpha_F M_t}{Y_{F,t}} = p_{F,t} \equiv e_t \left[1 + \vartheta \mu_t\right], \tag{13}$$

$$p_{M,t} \frac{\alpha_L M_t}{L_t} = w_t \tag{14}$$

$$p_{M,t} \frac{\alpha_K M_t}{K_t} = r_{K,t}. \tag{15}$$

$p_{F,t}$ represents the price of imported intermediate inputs. The complementary slackness condition for the collateral constraint is

$$e_t \mu_t \left[\kappa_t E_t \left(\frac{q_{t+1} k_{t+1}}{e_{t+1}} \right) + b_{t+1}^* - \vartheta Y_{F,t} \right] = 0, \tag{16}$$

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

For computational purposes we introduce a transformation to deal with the inequality constraint.

Let

$$\mu_t = (\max(0, \eta_t))^3 ;$$

then the complementary slackness conditions can be written

$$\kappa_t E_t \left(\frac{q_{t+1} k_{t+1}}{e_{t+1}} \right) + b^*_{t+1} - \vartheta Y_{F,t} = alm_t \equiv (\max(0, -\eta_t))^3$$

where η_t is a real number.

Combining equation (13)-(15) with the production function (1), yields a restriction on input prices:

$$\left(\frac{p_{F,t}}{\alpha_F} \right)^{\alpha_F} \left(\frac{w_t}{\alpha_L} \right)^{\alpha_L} \left(\frac{r_{K,t}}{\alpha_K} \right)^{\alpha_K} = A_t (p_{M,t})^{\alpha_F + \alpha_L + \alpha_K} (M_t)^{\alpha_F + \alpha_L + \alpha_K - 1}. \tag{17}$$

2.2 Final good producers

There are a continuum of monopolistically competitive final good producers with measure one, each of which differentiates the wholesale good into a specific variety of final goods. Each variety is an imperfect substitute for other varieties, implying that final good producers have a monopoly power over their varieties. All consumption varieties are aggregated into a consumption composite using the CES Dixit-Stiglitz aggregator

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

where Y_t represents total demand for consumption composites and $Y_t(i)$ denotes demand for variety i in period t. $\theta > 1$ is the elasticity of substitution between varieties. The higher θ, the more fierce the competition of varieties. Let $P_t(i)$ be the price of variety $Y_t(i)$. Cost minimization implies that the price for a consumption composite can be written as

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

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

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\theta} Y_t. \tag{18}$$

The technology employed by final goods firm i is linear in intermediates:

$$Y_t(i) = M_t(i). \tag{19}$$

Firms set prices in their own currency (producer currency pricing) and have chance to reset their prices each period but suffer a quadratic price adjustment cost (see Rotemberg 1982). Profits per period gained by firm i equals total revenues net of whole sale prices and of price adjustment costs

$$D_{H,t}(i) \equiv (1+\tau_H)\, P_t(i)Y_t(i) - P_{M,t}Y_t(i) - \frac{\phi_P}{2}\left(\frac{P_t(i)}{P_{t-1}(i)} - \pi\right)^2 Y_t(i)P_t(i),$$

where π is the inflation target and τ_H denotes a subsidy rate by the government used here to undo the monopoly power of final good producers. Firm i solves the problem

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

subject to demand for variety i (18) and production technology (19). The stochastic discount factor 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, $P_t(i) = P_t$, when resetting their prices. Consequently, the supply of each variety is identical $Y_t(i) = Y_t$. The optimality condition for price-setting can be simplified as

$$Y_t \left[(1+\tau_H) - \theta\left(1 + \tau_H - \frac{\phi_P}{2}(\pi_t - \pi)^2 - p_{M,t}\right)\right] - \phi_P Y_t \pi_t(\pi_t - \pi) - \frac{\phi_P}{2}(\pi_t - \pi)^2 Y_t + E_t\left[\Lambda_{t,t+1}\phi_P \pi_{t+1} Y_{t+1}(\pi_{t+} \right. \tag{20}$$

Real profits from intermediate producers are

$$d_{H,t} \equiv \frac{D_{H,t}}{P_t} = (1+\tau_H)Y_t - p_{M,t}Y_t - \frac{\phi_P}{2}(\pi_t - \pi)^2 Y_t = Y_t \left[(1+\tau_H) - p_{M,t} - \frac{\phi_P}{2}(\pi_t - \pi)^2\right]. \quad (21)$$

Notice that if there are no price adjustment costs, $\phi_P = 0$, and no monopoly power for providing varieties, $\tau_H = 1/(\theta - 1) > 0$, we then have $p_{M,t} = 1$ (no markup).

2.3 Market clearing conditions

The labor market clears if

$$l_t = L_t.$$

We also must have that aggregate consumption equals individual consumption:

$$c_t = C_t.$$

Assume that foreigners don't hold domestic currency denominated bonds. The domestic bond market clearing condition is then

$$b_{t+1} = 0. \quad (22)$$

Suppose that capital stock is fixed. The domestic capital market clearing condition yields

$$K_{t+1} = k_{t+1} = 1. \quad (23)$$

The wholesale good market clearing condition reads

$$\int_0^1 Y_t(i)di = \int_0^1 M_t(i)di = M_t. \quad (24)$$

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

$$Y_t \left[1 - \frac{\phi_P}{2}(\pi_t - \pi)^2\right] = C_t + X_t + (K_{t+1} - K_t)q_t. \tag{25}$$

Profits from final good producers are therefore

$$d_t = d_{H,t}. \tag{26}$$

2.4 Government policy

The lump-sum transfer is given by

$$T_t = -\tau_H Y_t P_t \tag{27}$$

We suppose the government fixes the production subsidy τ_H in order to offset the effects of monopoly power, as is standard in the monetary literature.

We consider two monetary regimes, fixed and flexible exchange rates.[3] To discipline our model we assume that the monetary authority (in the past) has set the nominal interest rate using a modified Taylor rule:

$$R_{t+1} = R\left(\frac{\pi_t}{\pi}\right)^{\alpha_\pi}\left(\frac{Y_t}{Y}\right)^{\alpha_Y}. \tag{28}$$

A variable without a superscript denotes the value of that variable at the deterministic steady state.[4] In the fixed exchange rate regime, nominal exchange rates are fixed, and therefore, domestic inflation is pinned down by foreign inflation and change of real exchange rate,

$$\pi_t = \frac{e_{t-1}}{e_t}\pi_t^* = \frac{e_{t-1}}{e_t}. \tag{29}$$

[3]Note that the change of nominal exchange rate is a function of the change of real exchange rate 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 real exchange rates.

[4]Fornaro (2013) studies a SOE model where purchasing power parity always holds. When the foreign price is fixed at $P_t^* = 1$, the domestic price equals $P_t = \mathcal{E}_t$. Stabilizing exchange rates is therefore equivalent to price stability policy.

Combining firm-households' budget constraints (8) with the relevant market clearing conditions and taxation policy (27), yields the country level resource constraint

$$C_t + \left(\frac{b^*_{t+1}}{R^*_{t+1}} - b^*_t\right) e_t = Y_t \left(1 - \frac{\phi_P}{2}(\pi_t - \pi)^2\right) - e_t Y_{F,t} - (K_{t+1} - K_t) q_t. \tag{30}$$

An alternative way to express this condition is to note that trade surpluses will finance net foreign assets:

$$X_t - e_t Y_{F,t} = \left(\frac{b^*_{t+1}}{R^*_{t+1}} - b^*_t\right) e_t. \tag{31}$$

The current account is given by

$$ca_t = X_t - e_t Y_{F,t} + \frac{e_t b^*_t}{R^*_t}(R^*_t - 1), \tag{32}$$

and capital account becomes

$$cca_t = -\left(\frac{B^*_{t+1}}{R^*_{t+1}} - \frac{B^*_t}{R^*_t}\right)\frac{e_t}{P^*_t} = -\left(\frac{b^*_{t+1}}{R^*_{t+1}} - \frac{b^*_t}{R^*_t}\right) e_t. \tag{33}$$

2.5 Competitive equilibrium (CE)

A 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 $\{w_t,\, q_t,\, \mu_t,\, R_{t+1},\, r_{K,t},\, e_t,\, p_{M,t}\}$, for $t = \cdots, 0, 1, 2, \cdots$, given policy variables $\{\tau_H,\, \pi_t\}$ chosen by the government such that (a) allocations solve households and firms' problem given the public policy and (b) prices clear corresponding markets. The system of competitive equilibrium conditions is

$$w_t = \chi L_t^{\nu},$$

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

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

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

$$e_t \left(1 + \mu_t \vartheta\right) Y_{F,t} = \alpha_F p_{M,t} Y_t,$$

$$w_t L_t = \alpha_L p_{M,t} Y_t,$$

$$r_{K,t} K_t = \alpha_K p_{M,t} Y_t,$$

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

$$\mu_t \geq 0$$

$$\kappa_t E_t \left(\frac{q_{t+1} k_{t+1}}{e_{t+1}} \right) + b^*_{t+1} - \vartheta Y_{F,t} \geq 0$$

$$Y_t = A_t (Y_{F,t})^{\alpha_F} L_t^{\alpha_L} K_t^{\alpha_K},$$

$$\begin{aligned} & Y_t \left[(1+\tau_H)(1-\theta) + \theta \frac{\phi_P}{2} (\pi_t - \pi)^2 + \theta p_{M,t} \right] - \phi_P Y_t \pi_t (\pi_t - \pi) \\ & - \frac{\phi_P}{2} (\pi_t - \pi)^2 Y_t + E_t \left[\beta \frac{U_c(t+1)}{U_c(t)} \phi_P \pi_{t+1} Y_{t+1} (\pi_{t+1} - \pi) \right] \\ = \; & 0. \end{aligned}$$

$$Y_t \left[1 - \frac{\phi_P}{2} (\pi_t - \pi)^2 \right] = C_t + e_t^{\rho} \zeta_t^* + (K_{t+1} - K_t) q_t,$$

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

$$K_{t+1} = K_t = 1$$

Monetary and fiscal policies: τ_H, R_{t+1}.

3 Constrained efficient allocation (CEA)

To gain insight into the nature of the distortions present in our model, we study a number of alternative allocations. First, we examine various different Taylor rules, including a strict inflation targeting rule that is optimal in a closed-economy setting. Then we explore various "social planning" allocations. For reasons outlined in Benigno et al. (2013) (that will also hold here), these allocations will not be good benchmarks against which to evaluate policy; instead, we use them to illuminate the inefficiencies present in our model and which tools can undo them.

We first investigate the constrained efficient allocation under different exchange rate regimes. In each regime, the social planner chooses π_t, b^*_{t+1}, k_{t+1} and $y_{F,t}$ for each household directly, but faces the same constraints as firm-households. We will be clear about what this means in each subsection.

3.1 Constrained efficient allocation under flexible exchange rate regime (CEAFL)

A social planner in the small economy maximizes a representative agent's lifetime utility, subject to the market clearing conditions (25), (24), the resource constraint (31), the production technology (1), the collateral constraint (7) and the Phillips curve (20). We can eliminate the wage rate using the labor supply condition $w_t = \chi L_t^{\nu}$. The problem solved by this planner is therefore

$$\max_{\{Y_t, C_t, Y_{F,t}, L_t, K_{t+1}, b^*_{t+1}, \tau_H, \pi_t, e_t, p_{M,t}\}} \left\{ E_0 \left[\sum_{t=0}^{\infty} \beta^t U\left(C_t, L_t\right) \right] \right\}$$

subject to

$$Y_t \left[1 - \frac{\phi_P}{2} (\pi_t - \pi)^2 \right] = C_t + e_t^{\rho} \zeta_t^* + (K_{t+1} - K_t) q_t, \tag{34}$$

$$e_t^{\rho-1} \zeta_t^* - Y_{F,t} = \frac{b^*_{t+1}}{R^*_{t+1}} - b^*_t, \tag{35}$$

$$\vartheta Y_{F,t} - b^*_{t+1} \le \kappa_t E_t \left(\frac{q_{t+1} K_{t+1}}{e_{t+1}} \right), \tag{36}$$

$$Y_t = A_t (Y_{F,t})^{\alpha_F} L_t^{\alpha_L} K_t^{\alpha_K}, \tag{37}$$

$$Y_t\left[(1+\tau_H)-\theta\left(1+\tau_H-\frac{\phi_P}{2}(\pi_t-\pi)^2-p_{M,t}\right)\right]-\phi_P Y_t\pi_t(\pi_t-\pi)- \tag{38}$$
$$\frac{\phi_P}{2}(\pi_t-\pi)^2 Y_t+E_t\left[\Lambda_{t,t+1}\phi_P\pi_{t+1}Y_{t+1}(\pi_{t+1}-\pi)\right]=0.$$

Two points are worth emphasizing in this problem. First, the only endogenous state variable in this problem is external borrowing b_t^*. The planner must have a rule for determining the two prices that appear in this problem, $q_t$and e_t. Following Bianchi and Mendoza (2013), we suppose the planner takes as given the competitive equilibrium mapping from the states (b_t^*, Z_t), where $Z_t$is the exogenous state vector, to the prices $q_t$and e_t; the planner can then only alter the prices by changing the states that are realized.[5]

Second, when monetary authority can freely change inflation, inflation will be set equal to target, $\pi_t=\pi$, since any deviation from the targeted inflation generates losses in output. The production subsidy rate $\tau_H=1/(\theta-1)$is set such that the price markup $p_{M,t}=1$in all time periods, which eliminates the Phillips curve equation from the problem.[6]

Let $\lambda_{1,t}$, $\lambda_{2,t}$and $\lambda_{2,t}\mu_t^{SP}e_t$be the Lagrange multipliers for the consumption composite market clearing condition, the resource constraint, and the collateral constraint respectively. The optimality conditions are

$$U_c(t)=\lambda_{1,t}, \tag{39}$$

$$-\frac{U_l(t)}{U_c(t)}=\chi L_t^{\nu}=\frac{\alpha_L Y_t}{L_t}, \tag{40}$$

$$U_c(t)\frac{\alpha_F Y_t}{Y_{F,t}}=\lambda_{2,t}e_t\left(1+\mu_t^{SP}\vartheta\right), \tag{41}$$

$$q_t=\frac{\lambda_{2,t}}{\lambda_{1,t}}\mu_t^{SP}\kappa_t E_t\left\{\frac{q_{t+1}e_t}{e_{t+1}}\right\}+E_t\left\{\beta\frac{U_c(t+1)}{U_c(t)}\left(\frac{\alpha_K Y_{t+1}}{K_{t+1}}+q_{t+1}\right)\right\}, \tag{42}$$

[5]Here, for consistency with the literature we call this a ”constrained efficient allocation”. Benigno et al. (2014) call this outcome ”conditionally efficient” and use constrained efficient for the allocation where the planner takes the pricing equation as given. For our model, the second notion of efficiency would not be recursive in (b_t^*, Z_t), significantly increasing the computational burden. For some problems the two allocations are equivalent (such as the endowment economy of Bianchi 2011). Marcet and Marimon (1998) contain a discussion of how to render the problem recursive using promises/Lagrange multipliers.

[6]This reduction is convenient because it eliminate future control variables π_{t+1} and Y_{t+1} from the current constraint set; as noted previously with respect to e_t and q_t, the problem with these variables present is not recursive in the natural state variables.

$$(\lambda_{2,t} - \lambda_{1,t})\rho e_t^{\rho-1}\zeta_t^* - \lambda_{2,t}\left(Y_{F,t} + \frac{b_{t+1}^*}{R_{t+1}^*} - b_t^*\right) = 0, \tag{43}$$

$$1 = \mu_t^{SP} R_{t+1}^* + \beta E_t\left\{\frac{\lambda_{2,t+1}}{\lambda_{2,t}}\frac{e_{t+1}}{e_t}R_{t+1}^*(1+\tau_{fl,t+1})\right\} \tag{44}$$

with

$$\tau_{fl,t+1} \equiv \frac{1}{\beta}\frac{\lambda_{2,t}}{\lambda_{2,t+1}}\frac{e_t}{e_{t+1}}\mu_t^{SP}\kappa_t K_{t+1}\frac{\partial(q_{t+1}(b_{t+1}^*; Z_{t+1})/e_{t+1}(b_{t+1}^*; Z_{t+1}))}{\partial b_{t+1}^*}.$$

The complementarity slackness condition is

$$\mu_t^{SP} e_t\left[\kappa_t E_t\left\{\frac{q_{t+1}K_{t+1}}{e_{t+1}}\right\} + b_{t+1}^* - \vartheta Y_{F,t}\right] = 0. \tag{45}$$

To implement the constrained efficient allocation, the government must set a state-contingent capital control $\tau_{fl,t+1}$ that replicates the effect of borrowing on the real price of assets (in terms of foreign goods); that derivative is ignored in the competitive equilibrium where agents are price-takers, and is the source of the "pecuniary externality problem". Note that $\tau_{fl,t+1} \geq 0$ and is equal to zero only if $\mu_t^{SP} = 0$; that is, the capital control is inactive only when the collateral constraint is not currently binding. Interestingly, the capital control for tomorrow is set today without reference to the multiplier tomorrow.

Notice that when $\lambda_{2,t} = \lambda_{1,t}$, equation (42) and (44) are equivalent to the conditions in Bianchi and Mendoza (2010) for an economy where real exchange rates are always equal to one. However, $\lambda_{2,t}$ and $\lambda_{1,t}$ are generally not equal in the current model. From the country resource constraint (35), we have

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

Combining this equation with equation (43) yields

$$(\lambda_{2,t} - \lambda_{1,t})\rho = \lambda_{2,t} > 0, \text{ with } \rho > 1, \tag{46}$$

We then have

$$\lambda_{2,t} = \frac{\rho}{\rho - 1}\lambda_{1,t} > \lambda_{1,t}$$

which states that the marginal product value of imported inputs is larger than the shadow cost of such inputs (see equation 41), $\frac{\alpha_F Y_t}{Y_{F,t}} > e_t\left(1 + \mu_t^{SP}\vartheta\right)$, implying that the social planner can take advantage of terms of trade manipulation to improve welfare. While in a competitive equilibrium with strict inflation targeting and zero capital controls, the imported input markets are competitive, which in the current case corresponds to equation (41) with $\lambda_{2,t} = \lambda_{1,t}$. The social planner not only internalizes the pecuniary externality induced by collateral constraints but also makes use of terms-of-trade manipulation to increase welfare. The elasticity of foreign demand for domestic consumption goods with respect to real exchange rate, ρ, plays a significant role in determining gains from terms of trade manipulation. The smaller ρ is, the larger monopoly power is owned by the domestic planner over its exports and it has an stronger incentive to manipulate its term of trade. It is clear that capital controls via state-contingent capital inflow tax $\tau_{fl,t+1}$ alone will not implement the constrained efficient allocation, we also need a tax on net exports $\tau_{NX} = \frac{\rho-1}{\rho}$.

Rearranging the optimality conditions for imports and capital price yields

$$\alpha_F Y_t = \frac{\rho}{\rho - 1} e_t Y_{F,t}\left(1 + \mu_t^{SP}\vartheta\right),$$

$$q_t = \frac{\rho}{\rho - 1}\mu_t^{SP}\kappa_t E_t\left\{\frac{q_{t+1}e_t}{e_{t+1}}\right\} + E_t\left\{\beta\frac{U_c(t+1)}{U_c(t)}\left(\frac{\alpha_K Y_{t+1}}{K_{t+1}} + q_{t+1}\right)\right\},$$

$$1 = \mu_t^{SP} R_{t+1}^* + \beta E_t\left\{\frac{U_c(t+1)}{U_c(t)}\frac{e_{t+1}}{e_t}R_{t+1}^*(1 + \tau_{fl,t+1})\right\}.$$

The equilibrium conditions can be simplified as a four-equation system with equations (42)-(45) in the unknowns $e_t, b_{t+1}^*, \mu_t^{SP}, q_t$. Other variables can be expressed as

$$K_t = 1,$$

$$\pi_t = \pi,$$

$$Y_{F,t} = e_t^{\rho-1}\zeta_t^* - \left(\frac{b_{t+1}^*}{R_{t+1}^*} - b_t^*\right),$$

$$L_t = \left[\frac{\alpha_L A_t (Y_{F,t})^{\alpha_F} K_t^{\alpha_K}}{\chi}\right]^{\frac{1}{1+\nu-\alpha_L}},$$

$$Y_t = A_t (Y_{F,t})^{\alpha_F} L_t^{\alpha_L} K_t^{\alpha_K},$$

$$C_t = Y_t - e_t^{\rho}\zeta_t^*,$$

$$\lambda_{1,t} = U_c(t) = \left(C_t - \chi\frac{L_t^{1+\nu}}{1+\nu}\right)^{-\gamma},$$

$$\lambda_{2,t} = U_c(t)\frac{\alpha_F Y_t}{Y_{F,t} e_t \left(1 + \mu_t^{SP}\vartheta\right)}.$$

3.2 Constrained efficient allocation under fixed exchange rate regime (CEAFI)

Under fixed exchange rates, the social planner maximizes representative agent's lifetime utility, subject to market clearing condition (25), (24), resource constraint (31), production technology (1), collateral constraint (7), price setting constraint (20) and constant nominal exchange rate $\mathcal{E}_t = \mathcal{E}$, which implies $\pi_t = \pi_t^* e_{t-1}/e_t$. The problem can be written as follows.

$$\max_{\{Y_t, C_t, Y_{F,t}, L_t, K_{t+1}, b_{t+1}^*, \tau_H, \pi_t, e_t, p_{M,t}\}} \left\{ E_0 \left[\sum_{t=0}^{\infty} \beta^t U\left(C_t, L_t\right)\right]\right\}$$

subject to

$$Y_t\left[1 - \frac{\phi_P}{2}(\pi_t - \pi)^2\right] = C_t + e_t^{\rho}\zeta_t^* + (K_{t+1} - K_t)q_t, \tag{47}$$

$$e_t^{\rho}\zeta_t^* - Y_{F,t}e_t = \left(\frac{b_{t+1}^*}{R_{t+1}^*} - b_t^*\right)e_t, \tag{48}$$

$$\vartheta Y_{F,t} - b_{t+1}^* \leq \kappa_t E_t\left(\frac{q_{t+1}K_{t+1}}{e_{t+1}}\right), \tag{49}$$

$$Y_t = A_t (Y_{F,t})^{\alpha_F} L_t^{\alpha_L} K_t^{\alpha_K}, \tag{50}$$

$$
\begin{aligned}
& Y_t \left[(1+\tau_H) - \theta \left(1 + \tau_H - \frac{\phi_P}{2}(\pi_t - \pi)^2 - p_{M,t} \right) \right] - \phi_P Y_t \pi_t (\pi_t - \pi) - \\
& \frac{\phi_P}{2}(\pi_t - \pi)^2 Y_t + E_t \left[\Lambda_{t,t+1} \phi_P \pi_{t+1} Y_{t+1} (\pi_{t+1} - \pi) \right] \\
= \; & 0,
\end{aligned} \tag{51}
$$

$$
\pi_t = \pi_t^* \frac{e_{t-1}}{e_t}. \tag{52}
$$

Now the endogenous state variables are external borrowing b_t^* and the lagged real exchange rate e_{t-1}. We can write the asset price and the real exchange rate in the constrained social planner's problem as a function of borrowing and exchange rate, $q_t(b_t^*, e_{t-1}; Z_t)$ and $e_t(b_t^*, e_{t-1}; Z_t)$. Notice also that there's a tension between gains from terms of trade manipulation via exchange rate movement e_t and inflation cost, since any associated deviation from the inflation target $\pi_t - \pi$ incurs a output loss when nominal exchange rates are fixed. The price markup $p_{M,t}$ is only determined by the Phillips curve. Therefore, we omit the Phillips curve in the social planner's problem. The production subsidy rate $\tau_H = 1/(\theta - 1)$ is set such that the price markup is $p_M = 1$ at the deterministic steady state.

Let $\lambda_{1,t}$, $\lambda_{2,t}$ and $\lambda_{2,t}\mu_t^{SP} e_t$ be the Lagrange multipliers for consumption composite market clearing condition, resource constraint and collateral constraint respectively. The optimality conditions are listed as follows

$$
U_c(t) = \lambda_{1,t}, \tag{53}
$$

$$
-\frac{U_l(t)}{U_c(t)} = \chi L_t^{\nu} = \frac{\alpha_L Y_t}{L_t} \left(1 - \frac{\phi_P}{2}(\pi_t - \pi)^2 \right), \tag{54}
$$

$$
U_c(t) \frac{\alpha_F Y_t}{Y_{F,t}} \left[1 - \frac{\phi_P}{2}(\pi_t - \pi)^2 \right] = \lambda_{2,t} e_t \left(1 + \mu_t^{SP} \vartheta \right), \tag{55}
$$

$$
q_t = \frac{\lambda_{2,t}}{\lambda_{1,t}} \mu_t^{SP} \kappa_t E_t \left\{ \frac{q_{t+1} e_t}{e_{t+1}} \right\} + E_t \left\{ \beta \frac{U_c(t+1)}{U_c(t)} \left(\frac{\alpha_K Y_{t+1}}{K_{t+1}} \left(1 - \frac{\phi_P}{2}(\pi_{t+1} - \pi)^2 \right) + q_{t+1} \right) \right\}, \tag{56}
$$

$$
(\lambda_{2,t} - \lambda_{1,t}) \rho (e_t)^{\rho - 1} \zeta_t^* - \lambda_{2,t} \left(Y_{F,t} + \frac{b_{t+1}^*}{R_{t+1}^*} - b_t^* \right)
$$

$$
\underbrace{+\lambda_{1,t}Y_t\phi_P(\pi_t-\pi)\frac{\pi_t}{e_t}-E_t\left\{\beta\lambda_{1,t+1}Y_{t+1}\phi_P(\pi_{t+1}-\pi)\frac{1}{e_{t+1}}\right\}}_{\text{Inflation adjustment costs}}
$$

$$
\underbrace{+\lambda_{2,t}\mu_t^{SP}e_t\kappa_tE_t\left\{K_{t+1}\frac{\partial(q_{t+1}(b^*_{t+1},e_t;Z_{t+1})/e_{t+1}(b^*_{t+1},e_t;Z_{t+1}))}{\partial e_t}\right\}}_{\text{Pecuniary externality}}=0, \tag{57}
$$

$$
1=\mu_t^{SP}R^*_{t+1}+\beta E_t\left\{\frac{\lambda_{2,t+1}}{\lambda_{2,t}}\frac{e_{t+1}}{e_t}R^*_{t+1}(1+\tau_{fe,t+1})\right\} \tag{58}
$$

with

$$
\tau_{fe,t+1}\equiv\frac{1}{\beta}\frac{\lambda_{2,t}}{\lambda_{2,t+1}}\frac{e_t}{e_{t+1}}\mu_t^{SP}\kappa_tK_{t+1}\frac{\partial(q_{t+1}(b^*_{t+1},e_t;Z_{t+1})/e_{t+1}(b^*_{t+1},e_t;Z_{t+1}))}{\partial b^*_{t+1}}.
$$

The complementarity slackness condition reads

$$
\mu_t^{SP}e_t\left[\kappa_tE_t\left\{\frac{q_{t+1}K_{t+1}}{e_{t+1}}\right\}+b^*_{t+1}-\vartheta Y_{F,t}\right]=0. \tag{59}
$$

Equation (57) shows that when choosing real exchange rates, the social planner takes into account of two additional effects of real exchange rates beyond merchandise trade and borrowing. One is price adjustment cost since the path of real exchange rates determines the path of domestic inflation under fixed exchange rate regime. The other is pecuniary externality caused by collateral constraints since asset price directly depends on the lagged real exchange rate.

The equilibrium conditions can be simplified as a four-equation system with equations (56)-(59) with variables $e_t, b^*_{t+1}, \mu_t^{SP}, q_t$. Other variables can be expressed as follows,

$$
K_t=1,
$$

$$
\pi_t=\pi_t^*\frac{e_{t-1}}{e_t}=\frac{e_{t-1}}{e_t},
$$

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

$$
L_t=\left[\left(1-\frac{\phi_P}{2}(\pi_t-\pi)^2\right)\frac{\alpha_LA_t(Y_{F,t})^{\alpha_F}K_t^{\alpha_K}}{\chi}\right]^{\frac{1}{1+\nu-\alpha_L}},
$$

$$Y_t = A_t(Y_{F,t})^{\alpha_F} L_t^{\alpha_L} K_t^{\alpha_K},$$

$$C_t = Y_t\left(1 - \frac{\phi_P}{2}(\pi_t - \pi)^2\right) - e_t^{\rho}\zeta_t^*,$$

$$\lambda_{1,t} = U_c(t) = \left(C_t - \chi\frac{L_t^{1+\nu}}{1+\nu}\right)^{-\gamma},$$

$$\lambda_{2,t} = \left(1 - \frac{\phi_P}{2}(\pi_t - \pi)^2\right) U_c(t)\frac{\alpha_F Y_t}{Y_{F,t}e_t\left(1 + \mu_t^{SP}\vartheta\right)}.$$

4 Optimal monetary policy (Ramsey allocation (RA))

When the only available policy instrument is monetary policy, say interest rate R_{t+1} and/or nominal exchange rate $\mathcal{E}_t$, how should monetary policy be set? We will focus on the optimal monetary policy and solve a Ramsey planner's problem in the flexible exchange rate regime. Here we focus on time-consistent monetary policy; emerging economies are generally viewed as lacking commitment (particularly since their central banks tend to be less independent), so the no-commitment case is a natural benchmark. It is also substantially easier to solve.

4.1 Optimal monetary policy under flexible exchange rate regime

Assume that the constant subsidy rate τ_H is set at $\tau_H = 1/(\theta - 1)$ to undo the monopoly power. Since the domestic authority has an incentive to manipulate terms of trade, we set a tax on imports equal to $\tau_{NX} = \rho/(\rho - 1)$ to get rid of the distortionary terms of trade manipulation. The monetary authority chooses the paths for inflation rates π_t to maximize a representative household's lifetime utility. Here we focus on the time-consistent optimal policy under discretion and look for a Markov-perfect equilibrium.[7] Let the value function for a representative domestic firm-household be $V(b_t^*, Z_t)$. The problem faced by the government is

$$V(b_t^*, Z_t) = \max_{\{\Xi\}}\left\{U\left(C_t - \chi\frac{L_t^{1+\nu}}{1+\nu}\right) + \beta E_t\left[V\left(b_{t+1}^*, Z_{t+1}\right)\right]\right\}$$

[7] Non-Markovian equilibria are very difficult to compute. For a study of non-Markovian optimal policy, see Dong (2015).

with

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

subject to

$$-q_t + \mu_t \kappa_t e_t E_t \left\{ \frac{q_{t+1}}{e_{t+1}} \right\} + E_t \left\{ \beta \frac{U_c(t+1)}{U_c(t)} (r_{K,t+1} + q_{t+1}) \right\} = 0, \tag{60}$$

$$-1 + \mu_t R^*_{t+1} + E_t \left\{ \beta \frac{U_c(t+1)}{U_c(t)} \frac{e_{t+1}}{e_t} R^*_{t+1} \right\} = 0, \tag{61}$$

$$e_t (1 + \mu_t \vartheta) Y_{F,t} - \alpha_F p_{M,t} Y_t = 0, \tag{62}$$

$$\chi L_t^{1+\nu} - \alpha_L p_{M,t} Y_t = 0, \tag{63}$$

$$r_{K,t} - \alpha_K p_{M,t} Y_t = 0, \tag{64}$$

$$\kappa_t E_t \left(\frac{q_{t+1}}{e_{t+1}} \right) + b^*_{t+1} - \vartheta Y_{F,t} - alm_t = 0, \tag{65}$$

$$-Y_t + A_t (Y_{F,t})^{\alpha_F} L_t^{\alpha_L} = 0, \tag{66}$$

$$\begin{aligned} & Y_t \left[(1+\tau_H)(1-\theta) + \theta \frac{\phi_P}{2} (\pi_t - \pi)^2 + \theta p_{M,t} \right] - \phi_P Y_t \pi_t (\pi_t - \pi) \\ & - \frac{\phi_P}{2} (\pi_t - \pi)^2 Y_t + E_t \left[\beta \frac{U_c(t+1)}{U_c(t)} \phi_P \pi_{t+1} Y_{t+1} (\pi_{t+1} - \pi) \right] \\ = \; & 0, \end{aligned} \tag{67}$$

$$Y_t \left[1 - \frac{\phi_P}{2} (\pi_t - \pi)^2 \right] - C_t - e_t^{\rho} \zeta_t^* = 0, \tag{68}$$

$$e_t^{\rho - 1} \zeta_t^* - Y_{F,t} - \left(\frac{b^*_{t+1}}{R^*_{t+1}} - b^*_t \right) = 0. \tag{69}$$

where μ_t and alm_t are defined as

$$\mu_t \equiv (\max(0, \eta_t))^2$$

$$alm_t \equiv (\max(0, -\eta_t))^2$$

and η_t is a real number.

Given policy functions for future variables $q(b^*_{t+1}, Z_{t+1})$, $e(b^*_{t+1}, Z_{t+1})$, $\eta(b^*_{t+1}, Z_{t+1})$, $p_M(b^*_{t+1}, Z_{t+1})$, $\pi(b^*_{t+1}, Z_{t+1})$ and value function $V(b^*_{t+1}, Z_{t+1})$, we can find b^*_{t+1}, L_t, C_t, Y_t, $Y_{F,t}$, q_t, η_t, $r_{K,t}$, e_t, $p_{M,t}$ and π_t at each combination of current savings b^*_t and the exogenous state Z_t to maximize the RHS of the objective function, based on equations (60)-(69).

Note that five variables can be eliminated analytically, and we need to solve the remaining six variables b^*_{t+1}, q_t, e_t, η_t, $p_{M,t}$ and π_t at each state (b^*_t, Z_t).

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

$$L_t = \left[\frac{p_{M,t}\alpha_L A_t (Y_{F,t})^{\alpha_F}}{\chi}\right]^{\frac{1}{1+\nu-\alpha_L}},$$

$$Y_t = A_t (Y_{F,t})^{\alpha_F} L_t^{\alpha_L},$$

$$r_{K,t} = \alpha_K p_{M,t} Y_t,$$

$$C_t = Y_t\left[1 - \frac{\phi_P}{2}(\pi_t - \pi)^2\right] - e_t^{\rho}\zeta_t^*.$$

4.2 Optimal capital controls under flexible exchange rate regime

Assume that the constant subsidy rate τ_H is set at $\tau_H = 1/(\theta-1)$ to undo the monopoly power in an economy without uncertainty. Note that the domestic authority has an incentive to manipulate terms of trade. We then set a tax on imports, $\tau_{NX} = \rho/(\rho-1)$, to get rid of the distortionary terms of trade manipulation. Assume that the monetary authority strictly targets inflation $\pi_t = 1$ and macroprudential authority chooses capital inflow tax $\tau_{C,t}$ to maximize a representative household's life-time utility. Given the capital inflow tax, the consumption Euler equation for foreign borrowing is given by

$$-1 + \mu_t R^*_{t+1} + E_t\left\{\beta\frac{U_c(t+1)}{U_c(t)}\frac{e_{t+1}}{e_t}R^*_{t+1}(1+\tau_{C,t})\right\} = 0 \tag{70}$$

Here we focus on the time-consistent optimal policy under discretion. Let the value function for a representative domestic firm-household be $V(b^*_t, Z_t)$. The problem faced by the government reads,

$$V(b_t^*, Z_t) = \max_{\{\Xi\}} \left\{ U\left(C_t - \chi \frac{L_t^{1+\nu}}{1+\nu} \right) + \beta E_t \left[V(b_{t+1}^*, Z_{t+1}) \right] \right\}$$

with

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

subject to

$$-q_t + \mu_t \kappa_t e_t E_t \left\{ \frac{q_{t+1}}{e_{t+1}} \right\} + E_t \left\{ \beta \frac{U_c(t+1)}{U_c(t)} (r_{K,t+1} + q_{t+1}) \right\} = 0, \tag{71}$$

$$e_t \left(1 + \mu_t \vartheta\right) Y_{F,t} - \alpha_F p_{M,t} Y_t = 0, \tag{72}$$

$$\chi L_t^{1+\nu} - \alpha_L p_{M,t} Y_t = 0, \tag{73}$$

$$r_{K,t} - \alpha_K p_{M,t} Y_t = 0, \tag{74}$$

$$\kappa_t E_t \left(\frac{q_{t+1}}{e_{t+1}} \right) + b_{t+1}^* - \vartheta Y_{F,t} - alm_t = 0, \tag{75}$$

$$-Y_t + A_t (Y_{F,t})^{\alpha_F} L_t^{\alpha_L} = 0, \tag{76}$$

$$Y_t \left[1 - \frac{\phi_P}{2} (\pi_t - \pi)^2 \right] - C_t - e_t^{\rho} \zeta_t^* = 0, \tag{77}$$

$$(e_t)^{\rho-1} \zeta_t^* - Y_{F,t} - \left(\frac{b_{t+1}^*}{R_{t+1}^*} - b_t^* \right) = 0. \tag{78}$$

where μ_t and alm_t are defined as

$$\mu_t \equiv (\max(0, \eta_t))^2$$

$$alm_t \equiv (\max(0, -\eta_t))^2$$

where η_t is a real number.

Given policy functions for future variables $q(b_{t+1}^*, Z_{t+1})$, $e(b_{t+1}^*, Z_{t+1})$, $\eta(b_{t+1}^*, Z_{t+1})$ and value function $V(b_{t+1}^*, Z_{t+1})$, we can find b_{t+1}^*, L_t, C_t, Y_t, $Y_{F,t}$, q_t, η_t, $r_{K,t}$ and e_t at each grid point (b_t^*, Z_t) to maximize the RHS of the objective function, based on equations (71)-(78).

Note that five variables can be solved analytically, and we need to solve the remaining four variables b^*_{t+1}, q_t, e_t and η_t at each grid point (b^*_t, Z_t).

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

$$L_t = \left[\frac{p_{M,t}\alpha_L A_t (Y_{F,t})^{\alpha_F}}{\chi}\right]^{\frac{1}{1+\nu-\alpha_L}},$$

$$Y_t = A_t (Y_{F,t})^{\alpha_F} L_t^{\alpha_L},$$

$$r_{K,t} = \alpha_K p_{M,t} Y_t,$$

$$C_t = Y_t\left[1 - \frac{\phi_P}{2}(\pi_t - \pi)^2\right] - e^{\rho}_t \zeta^*_t.$$

The optimal capital inflow tax $\tau_{C,t}$ is then given by

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

4.3 Optimal monetary and capital control policies under flexible exchange rate regime

Assume that the constant subsidy rate τ_H is set at $\tau_H = 1/(\theta - 1)$ to undo the monopoly power in an economy without uncertainty. Note that the domestic authority has an incentive to manipulate terms of trade. We then set a tax on exports, $\tau_{NX} = \rho/(\rho - 1)$, to get rid of the distortionary terms of trade manipulation. The authorities choose the paths for inflation rates π_t and capital inflow tax $\tau_{C,t}$ to maximize a representative household's life-time utility. Here we focus on the time-consistent optimal policy under discretion. Let the value function for a representative domestic firm-household be $V(b^*_t, Z_t)$. The problem faced by the government is

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

with

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

subject to

$$-q_t + \tau_{NX}\mu_t\kappa_t e_t E_t\left\{\frac{q_{t+1}}{e_{t+1}}\right\} + E_t\left\{\beta\frac{U_c(t+1)}{U_c(t)}(r_{K,t+1}+q_{t+1})\right\} = 0, \tag{79}$$

$$\tau_{NX}e_t\left(1+\mu_t\vartheta\right)Y_{F,t} - \alpha_F p_{M,t}Y_t = 0, \tag{80}$$

$$\chi L_t^{1+\nu} - \alpha_L p_{M,t}Y_t = 0, \tag{81}$$

$$r_{K,t} - \alpha_K p_{M,t}Y_t = 0, \tag{82}$$

$$\kappa_t E_t\left(\frac{q_{t+1}}{e_{t+1}}\right) + b^*_{t+1} - \vartheta Y_{F,t} - alm_t = 0, \tag{83}$$

$$-Y_t + A_t(Y_{F,t})^{\alpha_F}L_t^{\alpha_L} = 0, \tag{84}$$

$$\begin{aligned} &Y_t\left[(1+\tau_H)(1-\theta) + \theta\frac{\phi_P}{2}(\pi_t-\pi)^2 + \theta p_{M,t}\right] - \phi_P Y_t\pi_t(\pi_t-\pi) \\ &-\frac{\phi_P}{2}(\pi_t-\pi)^2Y_t + E_t\left[\beta\frac{U_c(t+1)}{U_c(t)}\phi_P\pi_{t+1}Y_{t+1}(\pi_{t+1}-\pi)\right] = 0, \end{aligned} \tag{85}$$

$$Y_t\left[1-\frac{\phi_P}{2}(\pi_t-\pi)^2\right] - C_t - e_t^{\rho}\zeta_t^* = 0, \tag{86}$$

$$(e_t)^{\rho-1}\zeta_t^* - Y_{F,t} - \left(\frac{b^*_{t+1}}{R^*_{t+1}} - b^*_t\right) = 0. \tag{87}$$

where μ_t and alm_t are defined as

$$\mu_t \equiv (\max(0,\eta_t))^2$$

$$alm_t \equiv (\max(0,-\eta_t))^2$$

where η_t is a real number.

Given policy functions for future variables $q(b^*_{t+1}, Z_{t+1})$, $e(b^*_{t+1}, Z_{t+1})$, $\eta(b^*_{t+1}, Z_{t+1})$, $p_M(b^*_{t+1}, Z_{t+1})$, $\pi(b^*_{t+1}, Z_{t+1})$ and value function $V(b^*_{t+1}, Z_{t+1})$, we can find b^*_{t+1}, L_t, $\tilde{C}_t$, Y_t, $Y_{F,t}$, q_t, η_t, $r_{K,t}$, e_t, $p_{M,t}$ and π_t at each state $(b^*_t,\ Z_t)$ to maximize the RHS of the objective function, based on equations (79)-(87).

Note that five variables can be solved analytically, and we need to solve the remaining six variables b^*_{t+1}, q_t, e_t, η_t, $p_{M,t}$ and π_t at each grid point (b^*_t, Z_t).

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

$$L_t = \left[\frac{p_{M,t}\alpha_L A_t (Y_{F,t})^{\alpha_F}}{\chi}\right]^{\frac{1}{1+\nu-\alpha_L}},$$

$$Y_t = A_t (Y_{F,t})^{\alpha_F} L_t^{\alpha_L},$$

$$r_{K,t} = \alpha_K p_{M,t} Y_t,$$

$$C_t = Y_t\left[1 - \frac{\phi_P}{2}(\pi_t - \pi)^2\right] - e_t^{\rho}\zeta_t^*.$$

The optimal capital inflow tax $\tau_{C,t}$ is then given by

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

5 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. The subjective discount $\beta = 0.975$, implying an annual interest rate of 10%. Parameters in the production function are set to match imports share (20% of GDP), labor share (70% of GDP) and external debt-GDP ratio (60%) for emerging economies. The share of working capital takes 10% of GDP, implying $\vartheta = 0.5$.

Nominal rigidity is introduced through a Rotemberg-style price adjustment cost. We set $\phi_P = 76$ as in Aruoba, Cuba-Borda, and Schorfheide (2013). TFP shocks and foreign interest rate shocks are taken from Faia and Iliopulos (2011). We discretize the continuous AR(1) process into a two-state Markov chain based on Tauchen and Hussey (1991). The leverage shock is based on Bianchi and Mendoza (2013). The leverage shock takes two values: $\kappa_L = 0.35$ and $\kappa_H = 0.45$. The collateral constraint binds mainly at the low leverage state. 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%.

Note that terms of trade manipulation may play an important role in affecting allocation and policy variables. We then consider different elasticities of substitution ρ faced by foreigners. In the baseline model, we set $\rho = 10$ and we also compare a high elasticity regime with $\rho = 5$ and a low elasticity regime $\rho = 51$.

6 Solution Method

We solve the model using time iteration, as in Coleman (1990) and Benigno et al. (2013). When necessary, we use a homotopy algorithm to solve the system of nonlinear equations (Eaves and Schmedders 1999). To solve the Ramsey problems we follow Benigno et al. (2012,2015) and solve the nonlinear optimization problem using feasible sequential quadratic programming (specifically, we use the NLPQLP routine developed by Klaus Schittkowski, who we thank for providing the code). All functions are approximated using B-splines. See also Devereux and Yu (2014).

7 Results

7.1 Competitive Equilibrium with Strict Inflation Targeting

To set our benchmark, we consider that monetary policy is set as would be optimal in a closed-economy; that is, a Taylor rule with a coefficient on inflation equal to plus infinity. We also impose the constant taxes used to correct the distortions due to monopoly power and the terms-of-trade

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 (L=1 at steady state)	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 (Aruoba, Cuba-Borda, and Schorfheide, 2013)	76
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 shock (RER=1)	0.1174
R^*	Steady state of world interest rate (Mendoza, 2010)	1.015
A	Steady state of TFP shock	1
ρ_A	Persistence of TFP shocks (Faia and Iliopulos, 2011)	0.95
σ_A	Standard deviation of TFP shocks (Faia and Iliopulos, 2011)	0.008
ρ_R	Persistence of foreign interest rate shocks (Faia and Iliopulos, 2011)	0.6
σ_R	Standard deviation of foreign interest rate shocks (Faia and Iliopulos, 2011)	0.00623
$p_{H,H}$	Transitional probability of high leverage to high leverage (Bianchi and Mendoza, 2013)	0.975
$p_{L,L}$	Transitional probability of low leverage to low leverage (Bianchi and Mendoza, 2013)	0.775
Policy variables		
α_π, α_Y, α_e	Coefficients in the Taylor rule	
τ_H	Subsidy to final goods producers	$\frac{1}{\theta-1}$
τ_{NX}	Gross subsidy to exports	$\frac{\rho}{\rho-1}$

manipulation.[8]

In this benchmark we detail the Fisherian deflation mechanism in our model. Suppose the economy is hit with a leverage shock that causes the constraint to bind today. Then b_{t+1} must rise (debt must fall) relative to where it would have been without the shock. This decline in debt leads to a decline in real consumption C_t and thus a rise in the relative cost of borrowing. Through the working capital constraint we therefore get a drop in the marginal product of capital today $r_{K,t}$. Since the shock is persistent, it is more likely to still be in the low leverage state tomorrow, meaning that $r_{K,t+1}$ will also be depressed; as a result, q_{t+1} is smaller as well, which feeds back into the collateral constraint through the term

$$E_t \left[\frac{q_{t+1}}{e_{t+1}} \right]$$

and further depresses borrowing. Figure (1) shows clearly the consequences of the constraint for the asset price; q_t declines sharply at debt levels where the constraint binds, and this decline is more severe in bad economic states.

We can see the dynamics of a crisis in Figures (2)-(3). The binding of the constraint in period 0 causes a persistent decline in foreign debt and a drop in output. The drop in output is not very persistent because labor snaps back quickly (the shock is a leverage shock and this shock only has substantial effects in the period it hits, since that is when the debt level must adjust). We can get more persistent declines if we hit the economy with a combination of persistent TFP declines, persistent world interest rate increases, and leverage shocks (these figures are averaged over all such events, and thus tend to overweight the primary source of collateral problems, the leverage shock).

Figures (4)-(5) show how the nominal interest rate and the real exchange rate are determined in equilibrium (note that inflation is constant and equal to target here because the Taylor coefficient is infinitely large, so the nominal interest rate tracks the real interest rate).

[8]Thus, we are not considering the incentive to use monetary policy to substitute for these taxes, as is done by Constinot, Lorenzoni, and Werning (2014). It seems clear that such a substitution is welfare-reducing, since the nominal interest rate is being put to a task it is not suited ideally to perform.

7.2 Optimal Monetary Policy

We start first by examining the optimal monetary policy under flexible exchange rates. Other than the constant subsidies to deal with monopoly power and the terms of trade, the nominal interest rate is the only tool under the control of the policymaker. Figures (4)-(5) show how the nominal interest rate and the real exchange rate are set. If the collateral constraint is not binding, the optimal inflation rate is constant and equal to the target. Once the constraint is binding, inflation increases with further increases in debt (although quantitatively the effect is not large); for brevity this graph is not presented, as it is an immediate implication of the previous two.

The real exchange rate rises as a result of the domestic inflation (a depreciation). The rise in e leads to a decline in the expected return on foreign debt (since it is denominated in foreign currency), arresting the capital outflow that would other arise and reducing the decline in consumption (Figure (**??**)). Note that the government today cannot directly attack the value of collateral, since borrowing is determined by the term

$$E_t \left[\frac{q_{t+1}}{e_{t+1}} \right]$$

which is outside the control of the current government. Instead, the government does the next best thing, which is to cut the expected real cost of borrowing

$$R^*_{t+1} \frac{e_{t+1}}{e_t}$$

by engineering a rise in e_t.

We again use Figures (2)-(3) to illustrate the dynamics of a crisis. Interestingly, optimal time-consistent monetary policy allows the crisis to generate a larger decline in consumption than the pure inflation targeting Taylor rule does. We can also see clearly in Figure (6) that optimal monetary supports the value of collateral – it is higher in all states than the CE (but, interestingly, not the CE with the subsidies; this curve cannot be seen because it lies essentially on top of the optimal monetary policy curve with only a slight difference for good states where the constraint is binding).

7.3 Welfare Gains

Finally, we turn to assessing the welfare consequences of our various monetary policy outcomes. Figures (7)-(8) show the welfare gains for the "best" and "worst" states (the best state has high TFP, low interest rates, and high leverage, the worst state has the opposite). We can see that the allocation in which the monetary authority does not have access to capital controls dominates the one where it does substantially, and that a pure inflation-targeting Taylor rule is generally dominated by both (only when debt is large does the Taylor rule beat the optimal monetary plus capital control allocation).

Welfare gains are similar in shape across states, but are a bit larger in bad times. Furthermore, the relative welfare losses associated with capital controls are much larger in the bad state than in the good one.

One might naturally ask why, if capital controls are welfare-reducing, the monetary authority does not simply set them to zero; after all, zero capital controls are always feasible given the lump-sum tax instrument is present. Here the lack of commitment plays an important role. Under commitment, the government solves a single agent optimization problem, so more options cannot be worse; that is, the government would simply set the controls to zero. But under discretion the government is playing a dynamic game, not solving an optimization problem, and as it turns out setting the capital control to zero is not an equilibrium.

The reasons are well known to the literature on the optimal capital income tax, which is structurally very similar to our capital control. Suppose the government today expects the government tomorrow to set $\tau_{C,t+1} = 0$; there will be only optimal monetary policy from tomorrow onward. The government today will then find it optimal to deviate and set a positive capital control. Thus, zero capital controls are not an equilibrium.[9] We conjecture, again based on the optimal capital tax literature, that the commitment case would feature a single period (or a finite number of periods) with positive capital controls followed by zero (or perhaps by capital controls that fluctuate around zero, as in Chari, Christiano, and Kehoe 1994).

[9] See Martin 2010.

8 Conclusion

This paper has studied the optimal conduct of monetary policy during a ”Sudden Stop” engineered by a binding collateral constraint. Our central results are (i) monetary policy should generate a currency depreciation during a crisis, in order to reduce the real cost of borrowing in foreign currency; (ii) capital controls are welfare-reducing during a crisis and should be kept out of the control of the central bank; and (iii) constrained efficient allocations are not a good guide for optimal policy.

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Figure 1: Asset Pricing

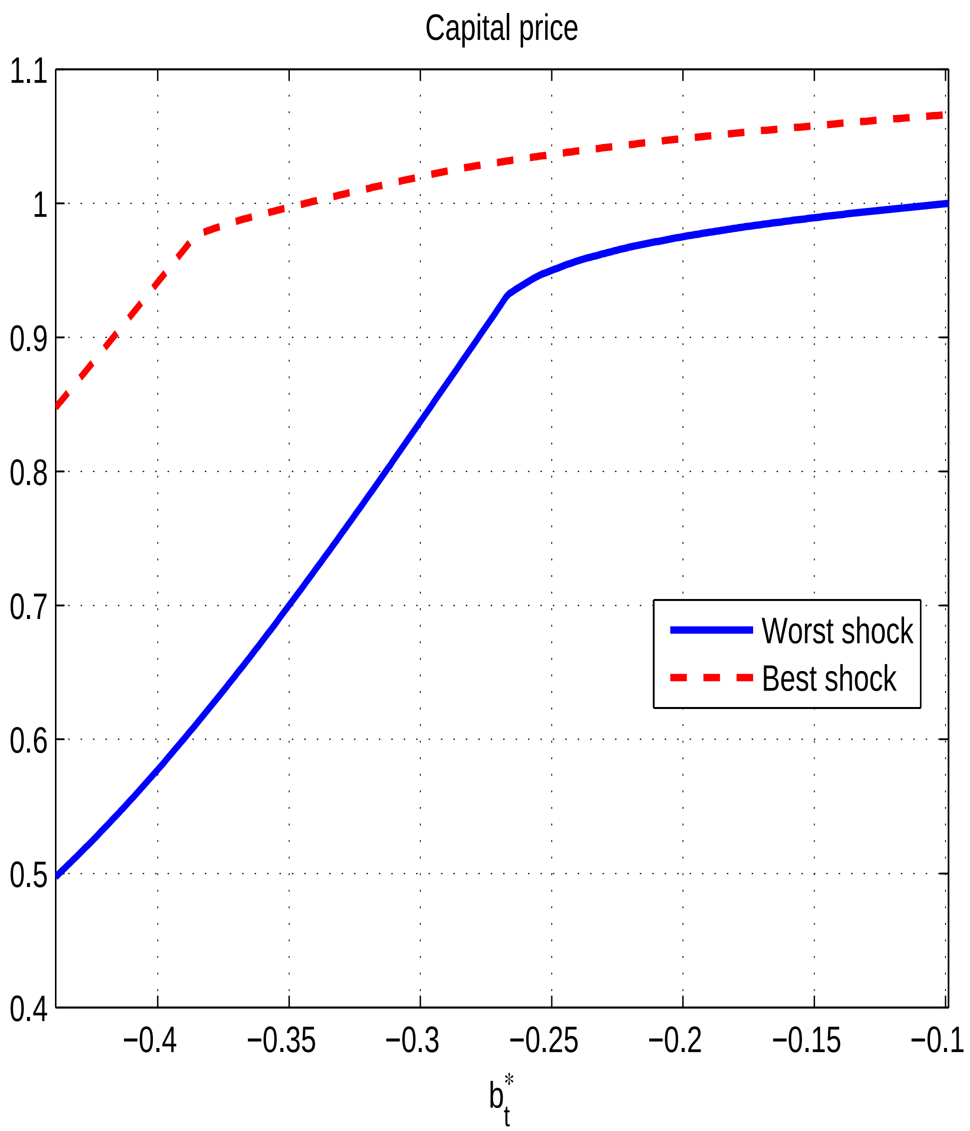


Figure 2: Dynamics of a Crisis

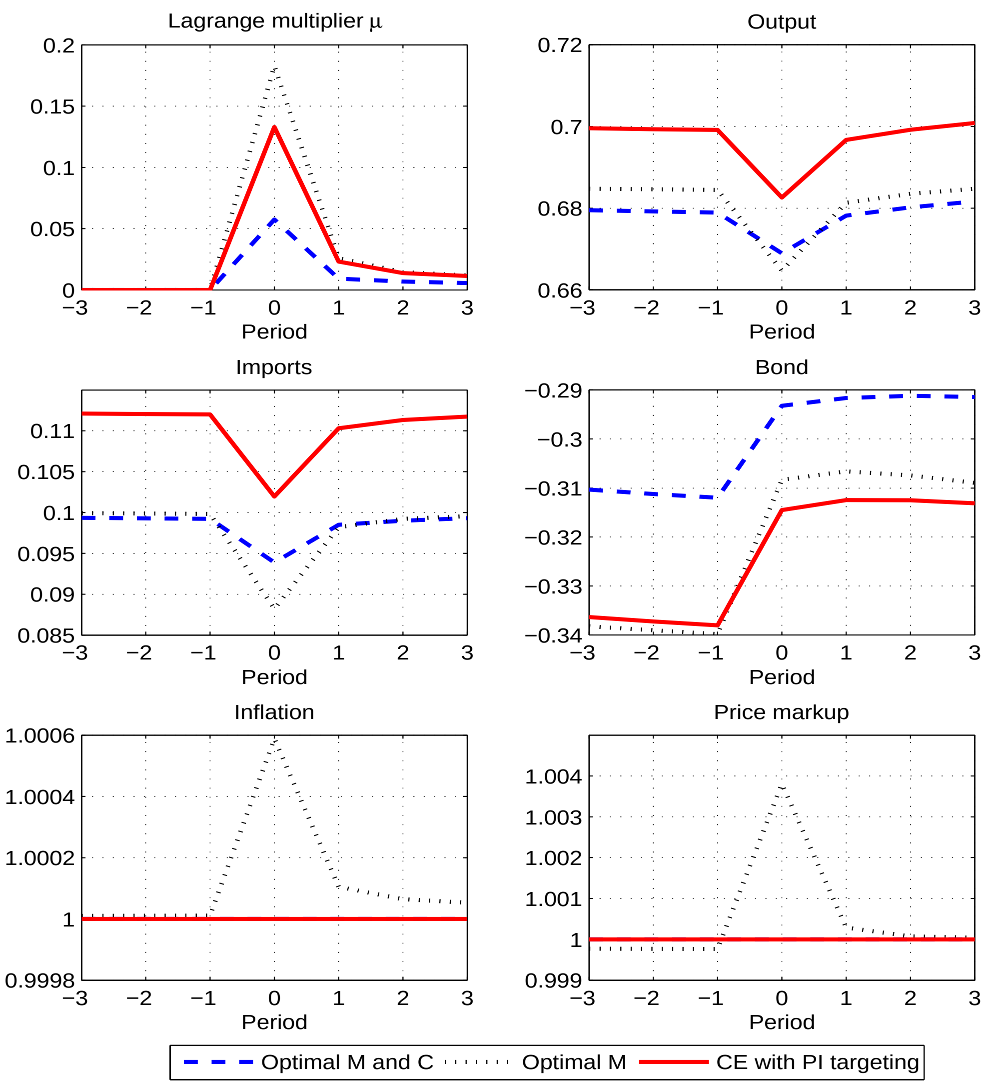
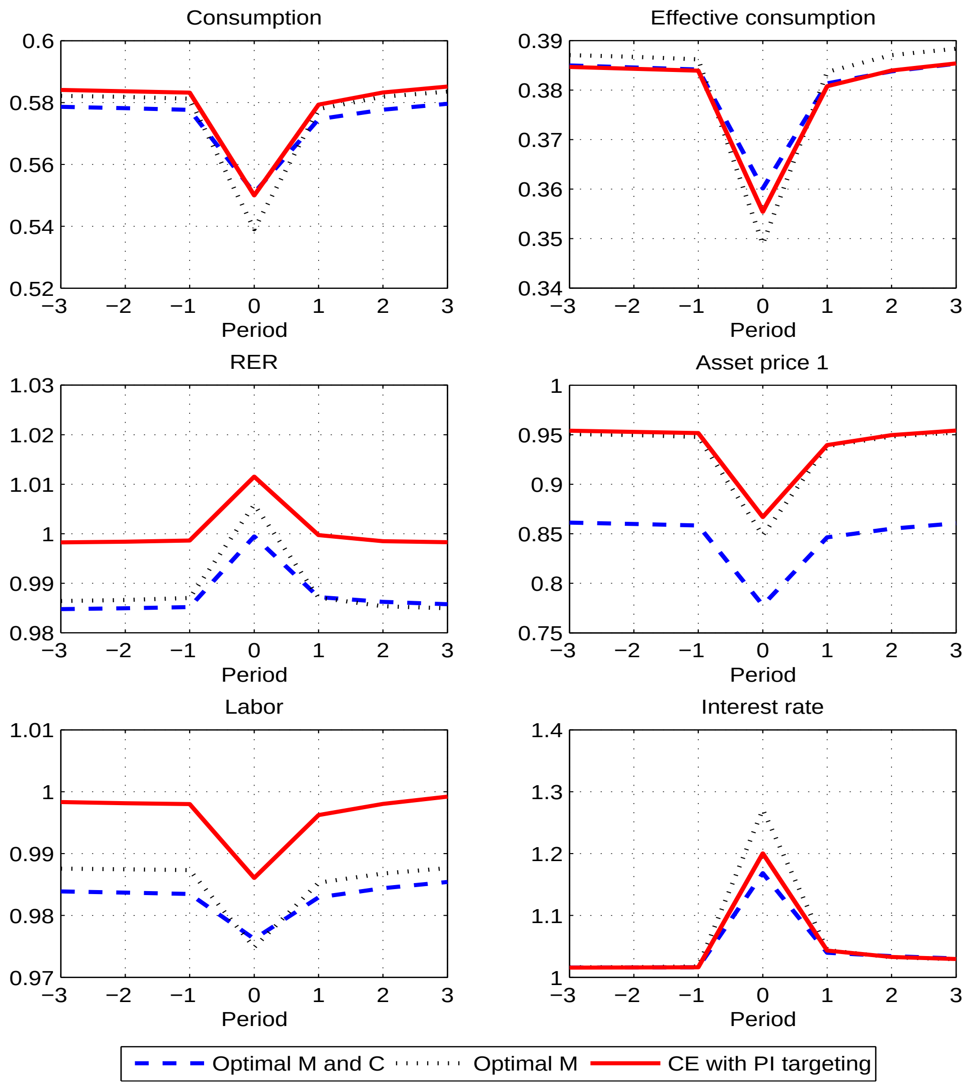
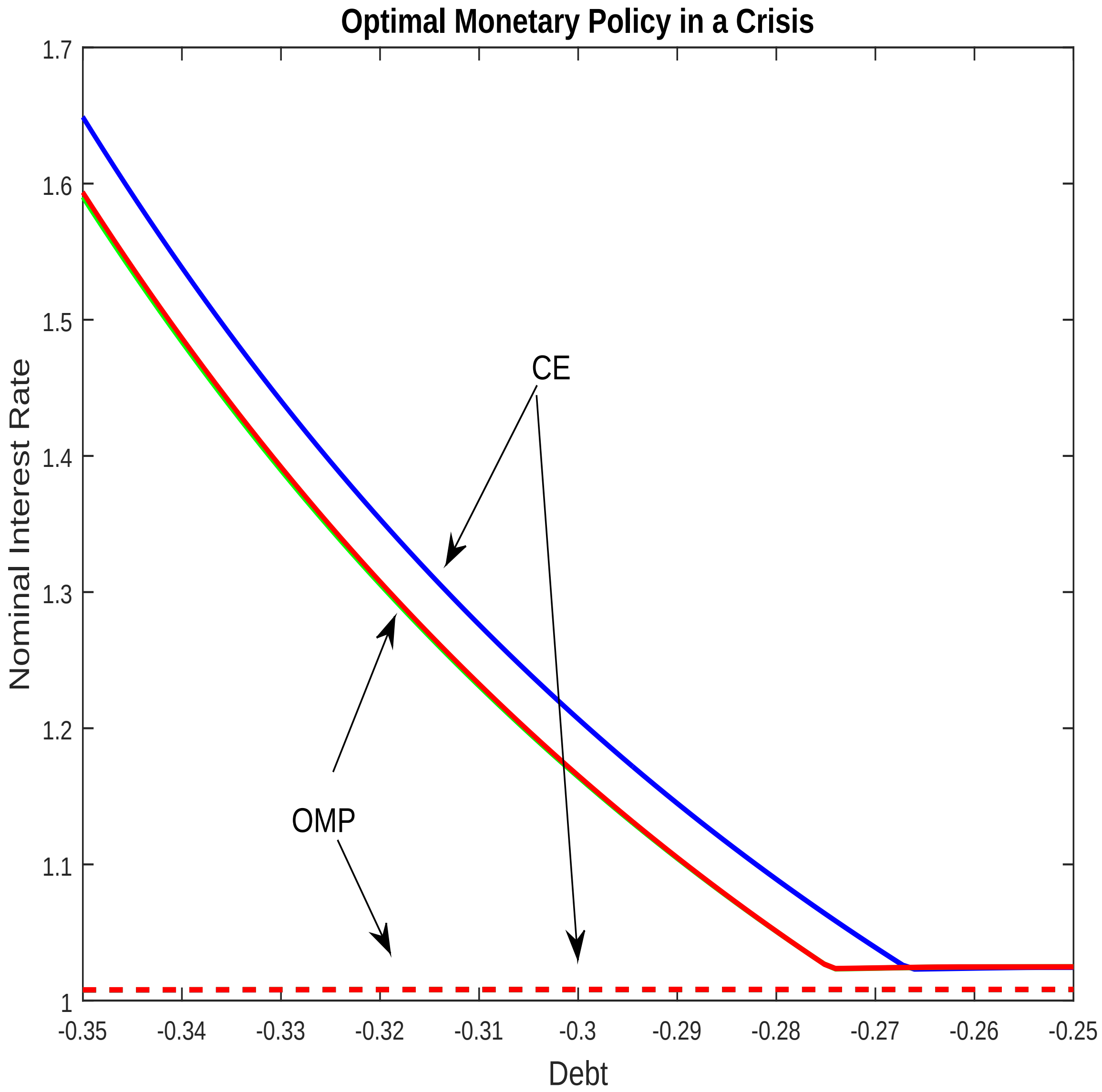
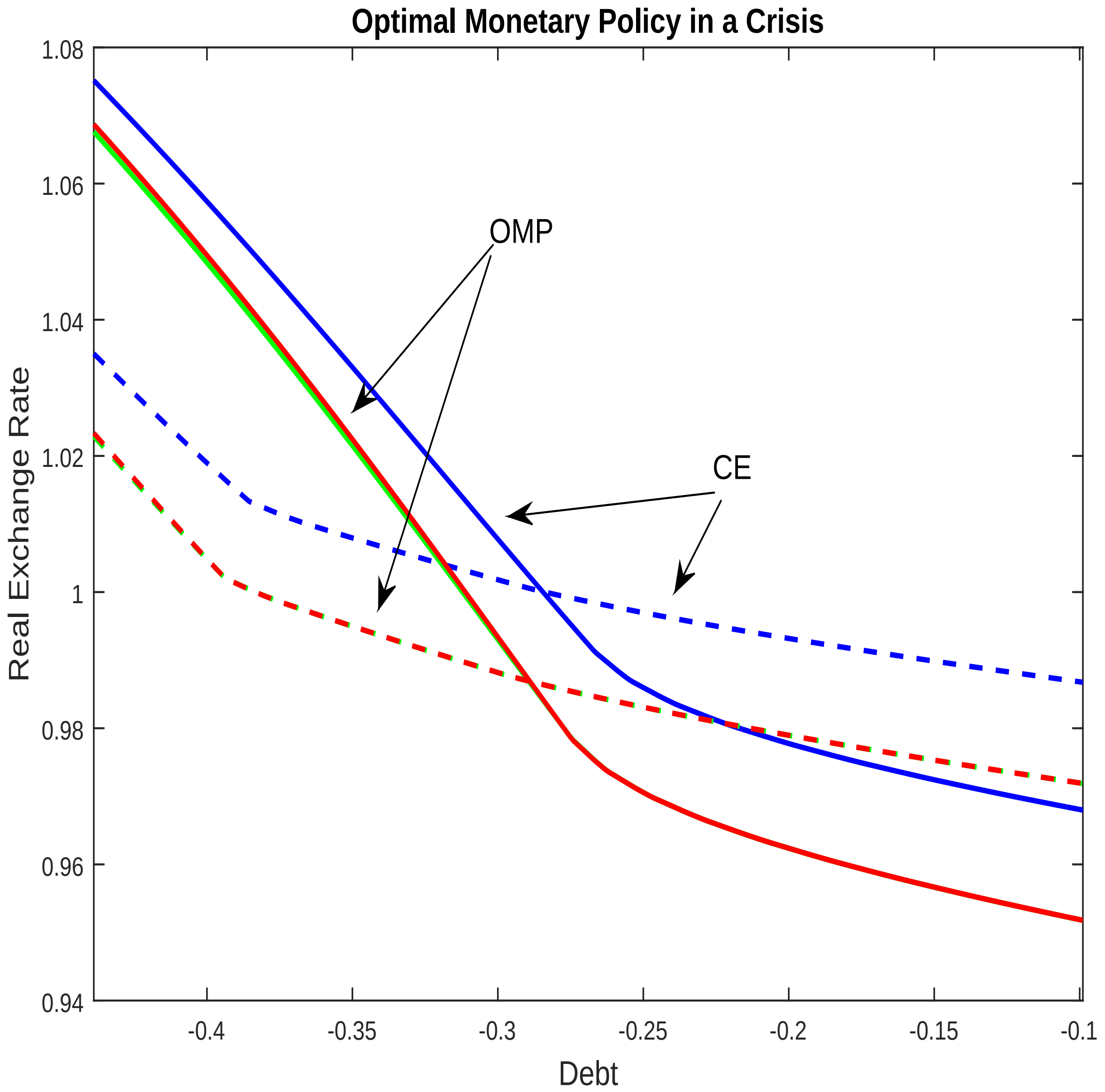


Figure 3: Dynamics of a Crisis

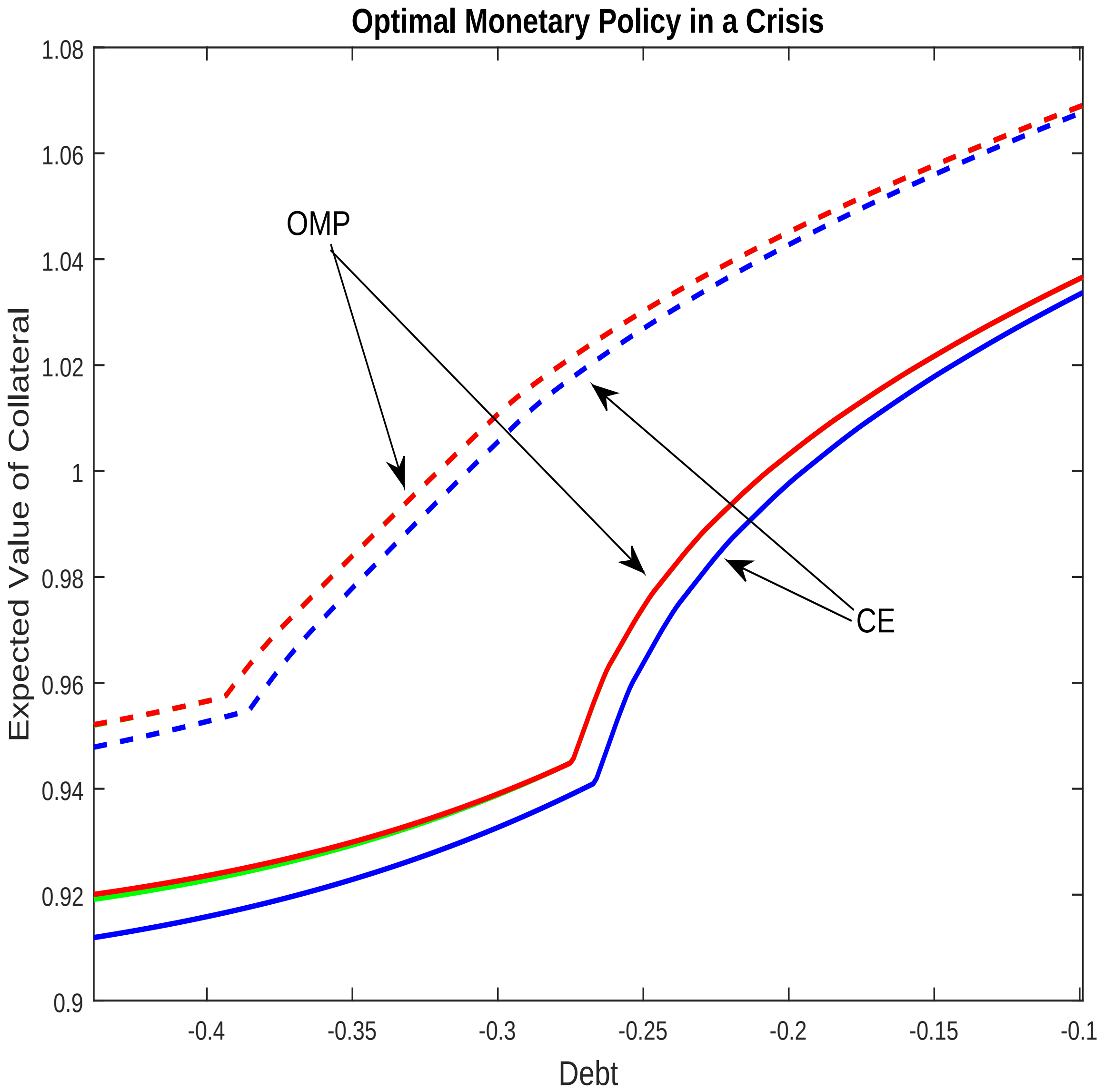




Optimal Monetary Policy in a Crisis
Nominal Interest Rate
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
CE
OMP
-0.35
-0.34
-0.33
-0.32
-0.31
-0.3
-0.29
-0.28
-0.27
-0.26
-0.25
Debt



Optimal Monetary Policy in a Crisis
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
Real Exchange Rate
OMP
CE
-0.4
-0.35
-0.3
-0.25
-0.2
-0.15
-0.1
Debt



Optimal Monetary Policy in a Crisis
Expected Value of Collateral
Debt
OMP
CE
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
-0.4
-0.35
-0.3
-0.25
-0.2
-0.15
-0.1

Figure 7: Welfare Gains

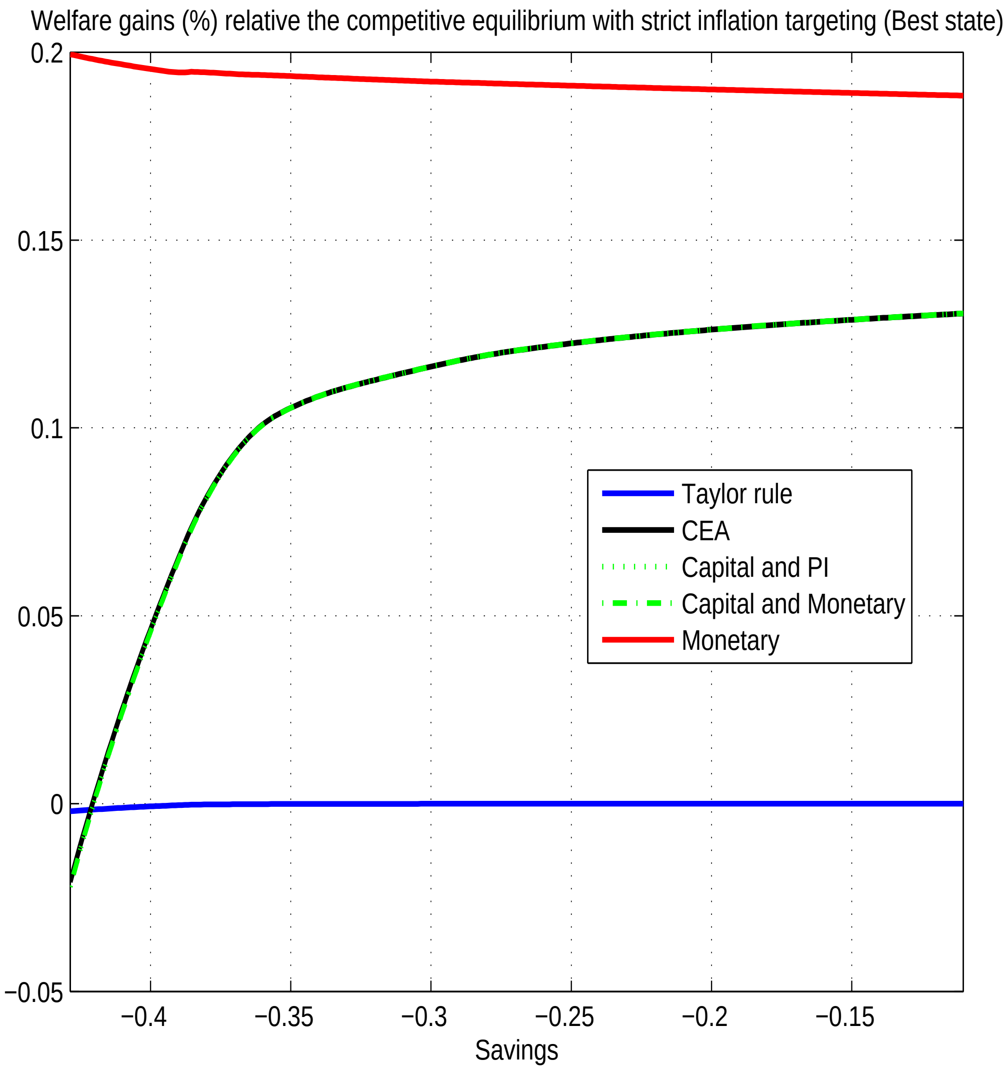


Figure 8: Welfare Gains