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MONETARY RULES IN EMERGING ECONOMIES WITH FINANCIAL MARKET IMPERFECTIONS

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Monetary Rules in Emerging Economies with Financial Market Imperfections*

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Abstract

We build a two-bloc emerging market - rest of the world model. The emerging market bloc incorporates partial transactions and liability dollarization, as well as financial frictions including a 'financial accelerator', where capital financing is partly or totally in foreign currency as in Gertler *et al.* (2003) and Gilchrist (2003)). Simulations of the model under various 'operational' monetary policy rules derived assuming that the central bank maximizes households' utility point to important results. First, we reaffirm the finding in the literature that financial frictions, especially when coupled with liability dollarization, severely increase the costs of a fixed exchange rate regime. By contrast, transactions dollarization has only a small impact on the choice of the monetary regime. Second, central banks in emerging economies with these frictions should not explicitly target the exchange rate; nor should they implicitly do so by choosing a CPI rather than domestic price inflation target. Third, with dollarization and frictions, the zero lower bound constraint on the nominal interest rate makes simple Taylor-type rules perform much worse in terms of stabilization performance than fully optimal monetary policy.

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Contents

1 Introduction

Over the past twenty years there has been a marked shift toward more flexible exchange rate regimes and more open capital accounts by both industrial and emerging market countries. Exchange rate targets accounted for over half of monetary policy regimes in 1985, but declined to just 5 percent in 2005, whilst in emerging market and other developing countries the share fell from 75 percent to 55 percent.

The move to more flexible exchange rate regimes has been accompanied by a variety of frameworks to conduct monetary policy, including inflation targeting, monetary targeting, and more eclectic approaches involving multiple objectives. In industrial countries, exchange rate pegs and monetary targets have been replaced by eclectic regimes, in G-3 countries, and by direct inflation targets almost everywhere else. In emerging market countries exchange rate pegs were replaced mainly by money targets through to the mid-1990s. Since then, however, money targets as well as exchange rate pegs have been replaced by direct inflation targets.

Over the next few years, the trend toward adoption of flexible exchange rate regimes, and inflation targeting in particular, is expected to continue. A recent IMF survey of 88 non-industrial countries found that more than half expressed a desire to move to explicit or implicit quantitative inflation targets. Moreover, nearly three quarters of these countries envisage a shift to full-fledged inflation targeting by 2010 (Batini *et al.* (2006)).

While there are undoubtedly countries where inflation targeting may not be a suitable framework, it is a flexible framework that can be adapted to particular needs of non-industrial countries. Non-industrial country inflation targeters face a number of challenges that differ in character or in degree from those faced in industrial economies. Calvo and Mishkin (2003) highlight five particularly important challenges for emerging market countries. These include: (i) weak public sector financial management; (ii) weak financial sector institutions and markets; (iii) low monetary policy credibility; (iv) extensive dollarization of financial liabilities; and (v) vulnerability to sharp changes in capital flows and international investor sentiment. In addition, many of these countries face considerably greater uncertainty about the structure of their economies, the monetary policy transmission mechanism, and the cyclical position of the economy than is typical of industrial country inflation targeters.

Our goal in this paper is to understand whether for non-industrial countries facing such challenges inflation targets are better or worse than (fix or soft) exchange rate targets. In particular we try to answer two central questions:

(1) How do financial frictions in emerging markets affect the transmission mechanism

of monetary policy and the volatility of the economy ?

(2) Can and should central banks in emerging markets facing financial frictions and vulnerable to combination of internal and external shocks try to balance inflation and exchange rate stabilization objectives?

We address these questions by developing a two-bloc emerging market – rest of the world DSGE model where, in the emerging market bloc there is a strong link between changes in the exchange rate and financial distress of household and firms. More precisely, we assume that: (a) there are financial frictions in the form of a 'financial accelerator', since firms are obliged to finance at least part of their capital requirements in foreign currency (see, Gertler *et al.* (2003) and Gilchrist (2003)); (b) domestic households hold both local and foreign currency money balances for transaction purposes; (c) the relative demand of foreign currency is endogenous to the extent of exchange rate stabilization by the central bank. The simultaneous assumption of (a)-(c) is novel in the literature.

We shock the model to understand how such financial frailties affect monetary transmission and inflation-output tradeoffs in the emerging market bloc. Using welfare analysis, we then compare the performance of monetary policy rules with different degrees of exchange rate flexibility and identify the rule for the emerging market central bank that responds to combination of internal and external shocks at the smallest welfare cost.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 sets out the form of monetary rules under investigation. In section 4 we we study an analytically tractable form of the model without capital. The focus here is on the effects of transactions dollarization. In Section 5 we explore the workings of the model and the monetary transmission mechanism in particular; we examine, under optimal policy, the volatility of key economic variables in the domestic economy and impulse response functions to a technology shock and to the country's borrowing premium shock. In section 6 we derive and compare alternative monetary policy rules that encompass various degrees of exchange rate flexibility, with, at one extreme, inflation targeting under a pure float, and at the other extreme, fixed exchange rates. Both domestic and consumer price inflation targets are examined. Section 7 addresses the requirement that monetary rules should be 'operational' in the sense that, in the face of shocks, the zero lower bound constraint on the nominal interest rate is very rarely hit. Section 8 provides concluding remarks.

2 The Model

We start from a standard two-bloc microfounded model along the lines of Obstfeld and Rogoff (1995) to then incorporate many of the nominal and real frictions that have been

shown to be empirically important in the study of closed economies (e.g. Smets and Wouters, 2003). The blocs are asymmetric and unequally-sized, each one with different household preferences and technologies. The single small open economy then emerges as the limit when the relative size of the larger bloc tends to infinity. Households work, save and consume tradable goods produced both at home and abroad. At home there are three types of firms: wholesale, retail and capital producers. As in Gertler *et al.* (2003), wholesale firms borrow from households to buy capital used in production and capital producers build new capital in response to the demand of wholesalers. Wholesalers' demand for capital in turn depends on their financial position which varies inversely with wholesalers' net worth.

There are three departures from the standard open-economy model that lead to interesting results. First, money enters utility in a non-separable way and results in a direct impact of the interest rate on the supply side.[1] Second, in the emerging market bloc, households derive utility from holding both domestic and foreign money (dollars) balances as in Felices and Tuesta (2006). Third, along the lines of Gilchrist (2003) (see also Cespedes *et al.* (2004)), part of the the debt of wholesale firms is financed in foreign currency (dollars), because it is impossible for firms to borrow 100 percent in domestic currency owing to 'original sin' type constraints. Finally, there a frictions in the world financial markets facing households as in Benigno (2001). Departures two and three add an additional dimension to openness itself, namely one whereby domestic agents not only hold foreign bonds and derive utility from consuming foreign-produced goods, as in standard open-economy models, but also borrow in foreign currency from domestic agents and derive utility from holding foreign money balances. Details of the model are as follows.

2.1 Households

Normalizing the total population to be unity, there are ν households in the 'home', emerging economy bloc and $(1-\nu)$ households in the 'foreign' bloc. A representative household h in the home bloc maximizes

$$E_t \sum_{t=0}^{\infty} \beta^t U\left(C_t(h), \frac{M_{H,t}(h)}{P_t}, \frac{M_{F,t}(h)S_t}{P_t}, L_t(h), \varepsilon_{C,t}, \varepsilon_{M_H,t}, \varepsilon_{M_F,t}, \varepsilon_{L,t}\right) \tag{1}$$

where E_t is the expectations operator indicating expectations formed at time t, β is the household's discount factor, $C_t(h)$ is a Dixit-Stiglitz index of consumption defined below in (5), $M_{H,t}(h)$ and $M_{F,t}(h)$ are end-of-period nominal domestic and foreign currency balances respectively, P_t is a Dixit-Stiglitz price index defined in (11) below, S_t is the nominal

[1] See Woodford (2003), Chapter 4. A 'cost channel', as in Ravenna and Walsh (2006), has a similar supply-side effect on the Phillips curve.

exchange rate and $L_t(h)$ are hours worked. $\varepsilon_{C,t}$ is a preference shock to the marginal utility of consumption and $\varepsilon_{M_H,t}$, $\varepsilon_{M_F,t}$ and $\varepsilon_{L,t}$ are shocks to demand for domestic currency, demand for foreign and labour supply respectively. An analogous symmetric intertemporal utility is defined for the 'foreign' representative household and the corresponding variables (such as consumption) are denoted by $C_t^*(h)$, etc.

We incorporate financial frictions facing households as in Benigno (2001). There are two risk-free one-period bonds denominated in the currencies of each bloc with payments in period t, $B_{H,t}$ and $B_{F,t}$ respectively in (per capita) aggregate. The prices of these bonds are given by

$$P_{B,t} = \frac{1}{1+R_{n,t}}; \quad P^*_{B,t} = \frac{1}{(1+R^*_{n,t})\phi(\frac{S_t B_{F,t}}{P_t})} \tag{2}$$

where $\phi(\cdot)$ captures the cost in the form of a risk premium for home households to hold foreign bonds. We assume $\phi(0) = 0$ and $\phi' < 0$. $R_{n,t}$ and $R^*_{n,t}$ denote the nominal interest rate over the interval $[t, t+1]$. For analytical convenience, the home households can hold foreign bonds, but foreign households cannot hold home bonds. Then the net and gross foreign assets in the home bloc are equal. The representative household h must obey a budget constraint:

$$\begin{aligned} & P_t C_t(h) + P_{B,t} B_{H,t}(h) + P^*_{B,t} S_t B_{F,t}(h) + M_{H,t}(h) + S_t M_{F,t}(h) + T_t \\ = \; & W_t(h) L_t(h) + B_{H,t-1}(h) + S_t B_{F,t-1}(h) + M_{H,t-1}(h) + S_t M_{F,t-1}(h) + \Gamma_t(h) \end{aligned} \tag{3}$$

where $W_t(h)$ is the wage rate, T_t are flat rate taxes and $\Gamma_t(h)$ are dividends from ownership of firms. In addition, if we assume that households' labour supply is differentiated with elasticity of supply η, then (as we shall see below) the demand for each consumer's labor supplied by ν identical households is given by

$$L_t(h) = \left(\frac{W_t(h)}{W_t}\right)^{-\eta} L_t \tag{4}$$

where $W_t = \left[\frac{1}{\nu}\sum_{r=1}^{\nu} W_t(h)^{1-\eta}\right]^{\frac{1}{1-\eta}}$ and $L_t = \left[\left(\frac{1}{\nu}\right)\sum_{r=1}^{\nu} L_t(h)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$ are the average wage index and average employment respectively.

Let the number of differentiated goods produced in the home and foreign blocs be n and $(1-n)$ respectively, again normalizing the total number of goods in the world at unity. We also assume that the the ratio of households to firms are the same in each bloc. It follows that n and $(1-n)$ (or ν and $(1-\nu)$) are measures of size. The per capita consumption index in the home bloc is given by

$$C_t(h) = \left[\mathrm{w}^{\frac{1}{\mu}} C_{H,t}(h)^{\frac{\mu-1}{\mu}} + (1-\mathrm{w})^{\frac{1}{\mu}} C_{F,t}(h)^{\frac{\mu-1}{\mu}}\right]^{\frac{\mu}{\mu-1}} \tag{5}$$

where μ is the elasticity of substitution between home and foreign goods,

$$\begin{aligned} C_{H,t}(h) &= \left[\left(\frac{1}{n}\right)^{\frac{1}{\zeta}} \sum_{f=1}^{n} C_{H,t}(f,h)^{(\zeta-1)/\zeta}\right]^{\zeta/(\zeta-1)} \\ C_{F,t}(h) &= \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\zeta}} \left(\sum_{f=1}^{1-n} C_{F,t}(f,h)^{(\zeta-1)/\zeta}\right)\right]^{\zeta/(\zeta-1)} \end{aligned}$$

where $C_{H,t}(f,h)$ and $C_{F,t}(f,h)$ denote the home consumption of household h of variety f produced in blocs H and F respectively and $\zeta > 1$ is the elasticity of substitution between varieties in each bloc. Analogous expressions hold for the foreign bloc which indicated with a superscript '$*$' and we impose $\zeta = \zeta^*$ for reasons that become apparent in section 2.2.2.[2] Weights in the consumption baskets in the two blocs are defined by

$$\mathrm{w} = 1-(1-n)(1-\omega)\,; \quad \mathrm{w}^* = 1-n(1-\omega^*) \tag{6}$$

In (6), ω, $\omega^* \in [0,1]$ are a parameters that captures the degree of 'bias' in the two blocs. If $\omega = \omega^* = 1$ we have autarky, while $\omega = \omega^* = 0$ gives us the case of perfect integration. In the limit as the home country becomes small $n \to 0$ and $\nu \to 0$. Hence $\mathrm{w} \to \omega$ and $\mathrm{w}^* \to 1$. Thus the foreign bloc becomes closed, but as long as there is a degree of home bias and $\omega > 0$, the home bloc continues to consume foreign-produced consumption goods.

Denote by $P_{H,t}(f)$, $P_{F,t}(f)$ the prices in domestic currency of the good produced by firm f in the relevant bloc. Then the optimal intra-temporal decisions are given by standard results:

$$C_{H,t}(r,f) = \left(\frac{P_{H,t}(f)}{P_{H,t}}\right)^{-\zeta} C_{H,t}(h)\,; \;\; C_{F,t}(r,f) = \left(\frac{P_{F,t}(f)}{P_{F,t}}\right)^{-\zeta} C_{F,t}(h) \tag{7}$$

$$C_{H,t}(h) = \mathrm{w}\left(\frac{P_{H,t}}{P_t}\right)^{-\mu} C_t(h)\,; \;\; C_{F,t}(h) = (1-\mathrm{w})\left(\frac{P_{F,t}}{P_t}\right)^{-\mu} C_t(h) \tag{8}$$

where aggregate price indices for domestic and foreign consumption bundles are given by

$$P_{H,t} = \left[\frac{1}{n}\sum_{f=1}^{n} P_{H,t}(f)^{1-\zeta}\right]^{\frac{1}{1-\zeta}} \tag{9}$$

$$P_{F,t} = \left[\frac{1}{1-n}\sum_{f=1}^{1-n} P_{F,t}(f)^{1-\zeta}\right]^{\frac{1}{1-\zeta}} \tag{10}$$

[2]Consistently we adopt a notation where subscript H or F refers to goods H or F produced in the home and foreign bloc respectively. The presence (for the foreign bloc) or the absence (for the home bloc) of a superscript '$*$' indicates where the good is consumed or used as an input. Thus $C^*_{H,t}$ refers to the consumption of the home good by households in the foreign bloc. Parameter w and w^* refer to the home and foreign bloc respectively, etc.

and the domestic consumer price index P_t given by

$$P_t = \left[\mathrm{w}(P_{H,t})^{1-\mu} + (1-\mathrm{w})(P_{F,t})^{1-\mu}\right]^{\frac{1}{1-\mu}} \tag{11}$$

with a similar definition for the foreign bloc.

Let S_t be the nominal exchange rate. The law of one price applies to differentiated goods so that $\frac{S_t P^*_{F,t}}{P_{F,t}} = \frac{S_t P^*_{H,t}}{P_{H,t}} = 1$. Then it follows that the real exchange rate $RER_t = \frac{S_t P^*_t}{P_t}$ and the terms of trade, defined as the domestic currency relative price of imports to exports $\mathcal{T}_t = \frac{P_{F,t}}{P_{H,t}}$, are related by the relationship

$$RER_t \equiv \frac{S_t P^*_t}{P_t} = \frac{\left[\mathrm{w}^* + (1-\mathrm{w}^*)\mathcal{T}_t^{\mu^*-1}\right]^{\frac{1}{1-\mu^*}}}{\left[1-\mathrm{w}+\mathrm{w}\mathcal{T}_t^{\mu-1}\right]^{\frac{1}{1-\mu}}} \tag{12}$$

Thus if $\mu = \mu^*$, then $RER_t = 1$ and the law of one price applies to the aggregate price indices iff $\mathrm{w}^* = 1-\mathrm{w}$. The latter condition holds if there is no home bias. If there is home bias, the real exchange rate appreciates (RER_t falls) as the terms of trade deteriorates.

We assume flexible wages. Then maximizing (1) subject to (3) and (4), treating habit as exogenous, and imposing symmetry on households (so that $C_t(h) = C_t$, etc) yields standard results:

$$P_{B,t} = \beta E_t\left[\frac{U_{C,t+1}}{U_{C,t}}\frac{P_t}{P_{t+1}}\right] \tag{13}$$

$$U_{M_H,t} = U_{C,t}\left[\frac{R_{n,t}}{1+R_{n,t}}\right] \tag{14}$$

$$U_{M_F,t} = U_{C,t}\left[\frac{R^*_{n,t}}{1+R^*_{n,t}}\right] \tag{15}$$

$$\frac{W_t}{P_t} = -\frac{\eta}{(\eta-1)}\frac{U_{L,t}}{U_{C,t}} \tag{16}$$

where $U_{C,t}$, $U_{M_H,t}$, $U_{M_F,t}$ and $-U_{L,t}$ are the marginal utility of consumption, money holdings in the two currencies and the marginal disutility of work respectively. Taking expectations of (13), the familiar Keynes-Ramsey rule, and its foreign counterpart, we arrive at the *modified risk-sharing condition*

$$\frac{P_{B,t}}{P^*_{B,t}} = \frac{E_t\left[U_{C,t+1}\frac{P_t}{P_{t+1}}\right]}{E_t\left[U_{C,t+1}\frac{S_{t+1}P_t}{S_t P_{t+1}}\right]} \tag{17}$$

In (14), the demand for money balances depends positively on the marginal utility of consumption and negatively on the nominal interest rate. If, as is common in the literature, one adopts a utility function that is separable in money holdings, then given the central

bank's setting of the latter and ignoring seignorage in the government budget constraint money demand is completely recursive to the rest of the system describing our macro-model. However separable utility functions are implausible (see Woodford (2003),chapter 3, section 3.4) and following Felices and Tuesta (2006) we will not go down this route. Finally, in (16) the real disposable wage is proportional to the marginal rate of substitution between consumption and leisure, $-\frac{U_{L,t}}{U_{C,t}}$, and the constant of proportionality reflects the market power of households that arises from their monopolistic supply of a differentiated factor input with elasticity η.

2.2 Firms

There are three types of firms, wholesale, retail and capital producers. Wholesale firms are run by risk-neutral entrepreneurs who purchase capital and employ household labour to produce a wholesale goods that is sold to the retail sector. The wholesale sector is competitive, but the retail sector is monopolistically competitive. Retail firms differentiate wholesale good at no resource cost and sell the differentiated (repackaged) goods to households. The capital goods sector is competitive and converts the final good into capital. The details are as follows.

2.2.1 Wholesale Firms

Wholesale goods are homogeneous and produced by entrepreneurs who combine differentiated labour and capital with and a technology

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha} \tag{18}$$

where K_t is beginning-of-period t capital stock,

$$L_t = \left[\left(\frac{1}{\nu} \right)^{\frac{1}{\eta}} \sum_{r=1}^{\nu} L_t(h)^{(\eta-1)/\eta} \right]^{\eta/(\eta-1)} \tag{19}$$

where we recall that $L_t(h)$ is the labour input of type h, and A_t is an exogenous shock capturing shifts to trend total factor productivity in this sector.[3] Minimizing wage costs $\sum_{h=1}^{\nu} W_t(h) L_t(h)$ gives the demand for each household's labour as

$$L_t(h) = \left(\frac{W_t(h)}{W_t} \right)^{-\eta} L_t \tag{20}$$

[3]Following Gilchrist *et al.* (2002) and Gilchrist (2003), we ignore the managerial input into the production process and later, consistent with this, we ignore the contribution of the managerial wage in her net worth.

Wholesale goods sell at a price $P^W_{H,t}$ in the home bloc. Equating the marginal product and cost of aggregate labour gives

$$W_t = P^W_{H,t}(1-\alpha)\frac{Y_t}{L_t} \tag{21}$$

Let Q_t be the real market price of capital in units of total household consumption. Then noting that profits per period are $P^W_{H,t}Y_t - W_tL_t = \alpha P^W_{H,t}Y_t$, using (21), the expected return on capital, acquired at the beginning of period t, over the period is given by

$$E_t(1+R^k_t) = \frac{\frac{P^W_{H,t}}{P_t}\alpha\frac{Y_t}{K_t} + (1-\delta)E_t[Q_{t+1}]}{Q_t} \tag{22}$$

where δ is the depreciation rate of capital. This expected return must be equated with the expected cost of funds over $[t, t+1]$, taking into account credit market frictions. Wholesale firms borrow in both home and foreign currency, with proportion of the former given by $\varphi \in [0,1]$, so that the expected return is

$$\begin{aligned}
& (1+\Theta_t)\varphi E_t\left[(1+R_{n,t})\frac{P_t}{P_{t+1}}\right] + (1+\Theta_t)(1-\varphi)E_t\left[(1+R^*_{n,t})\frac{P^*_t}{P^*_{t+1}}\frac{RER_{t+1}}{RER_t}\right] \\
= \;& (1+\Theta_t)\left[\varphi E_t\left[(1+R_t)\right] + (1-\varphi)E_t\left[(1+R^*_t)\frac{RER_{t+1}}{RER_t}\right]\right] \\
= \;& (1+\Theta_t)E_t\left[1+R_t\right]
\end{aligned} \tag{23}$$

since UIP holds. In (23), $RER_t \equiv \frac{P^*_t S_t}{P_t}$ is the real exchange rate, $R_{t-1} \equiv \left[(1+R_{n,t-1})\frac{P_{t-1}}{P_t}\right] - 1$ is the ex post real interest rate over $[t-1, t]$ and $\Theta_t \geq 0$ is the external finance premium given by

$$\Theta_t = \Theta\left(\frac{B_t}{N_t}\right) \;;\; \Theta'(\cdot) > 0,\; \Theta(0) = 0,\; \Theta(\infty) = \infty \tag{24}$$

where $B_t = Q_tK_t - N_t$ is bond-financed acquisition of capital in period t and N_t is the beginning-of-period t entrepreneurial net worth, the equity of the firm. Note that the *ex post* return at the beginning of period t, R^k_{t-1}, is given by

$$1 + R^k_{t-1} = \frac{\frac{P^W_{H,t-1}}{P_{t-1}}\alpha\frac{Y_{t-1}}{K_{t-1}} + (1-\delta)Q_t}{Q_{t-1}} \tag{25}$$

and this can deviate from the *ex ante* return on capital.

Assuming that entrepreneurs exit with a given probability $1-\xi_e$, net worth accumulates according to

$$N_t = \xi_e V_t \tag{26}$$

where V_t the net value carried over from the previous period is given by

$$\begin{aligned}
V_t \;=\; & \Big[(1+R^k_{t-1})Q_{t-1}K_{t-1} \\
- \; & (1+\Theta_{t-1})\left(\varphi(1+R_{t-1}) + (1-\varphi)(1+R^*_{t-1})\frac{RER_t}{RER_{t-1}}\right)(Q_{t-1}K_{t-1} - N_{t-1})\Big]
\end{aligned} \tag{27}$$

Note that in (27), $(1+R^k_{t-1})$ is the ex post return on capital acquired at the beginning of period $t-1$, $(1+R_{t-1})$ is the ex post real cost of borrowing in home currency and $(1+R^*_{t-1})\frac{RER_t}{RER_{t-1}}$ is the ex post real cost of borrowing in foreign currency. Also note that net worth N_t at the beginning of period t is a non-predetermined variable since the ex post return depends on the current market value Q_t, itself a non-predetermined variable.

Exiting entrepreneurs consume C^e_t, the remaining resources, given by

$$C^e_t = (1-\xi_e)V_t \tag{28}$$

of which consumption of the domestic good, as in (8), is given by

$$C^e_{H,t} = \mathrm{w}\left(\frac{P_{H,t}}{P_t}\right)^{-\mu} C^e_t \tag{29}$$

2.2.2 Retail Firms

Retail firms are monopolistically competitive, buying wholesale goods and differentiating the product at a fixed resource cost F. In a free-entry equilibrium profits are driven to zero. Retail output for firm f is then $Y_t(f) = Y^W_t(f) - F$ where Y^W_t is produced according to production technology (18). Retail firms set prices of differentiated goods according to the following. Assume that there is a probability of $1-\xi_H$ at each period that the price of each good f is set optimally to $\hat{P}_{H,t}(f)$. If the price is not re-optimized, then it is held constant.[4] For each producer f the objective is at time t to choose $\hat{P}_{H,t}(f)$ to maximize discounted profits

$$E_t \sum_{k=0}^{\infty} \xi^k_H D_{t,t+k} Y_{t+k}(f) \left[\hat{P}_{H,t}(f) - P_{H,t+k}\mathrm{MC}_{t+k}\right]$$

where $D_{t,t+k}$ is the discount factor over the interval $[t, t+k]$, subject to a common[5] downward sloping demand from domestic consumers and foreign importers of elasticity ζ as in (7) and $MC_t = \frac{P^W_{H,t}}{P_{H,t}}$ are marginal costs. The solution to this is

$$E_t \sum_{k=0}^{\infty} \xi^k_H D_{t,t+k} Y_{t+k}(f) \left[\hat{P}_{Ht}(f) - \frac{\zeta}{(\zeta-1)} P_{H,t+k}\mathrm{MC}_{t+k}\right] = 0 \tag{30}$$

and by the law of large numbers the evolution of the price index is given by

$$P^{1-\zeta}_{H,t+1} = \xi_H \left(P_{H,t}\right)^{1-\zeta} + (1-\xi_H)(\hat{P}_{H,t+1}(f))^{1-\zeta} \tag{31}$$

[4] Thus we can interpret $\frac{1}{1-\xi_H}$ as the average duration for which prices are left unchanged.

[5] Recall that we have imposed a symmetry condition $\zeta = \zeta^*$ at this point; i.e., the elasticity of substitution between differentiated goods produced in any one bloc is the same for consumers in both blocs.

2.2.3 Capital Producers

As in Smets and Wouters (2003), we introduce a the delayed response of investment observed in the data. Capital producers combine existing capital, K_t, leased from the entrepreneurs to transform an input I_t, gross investment, into new capital according to

$$K_{t+1} = (1-\delta)K_t + (1 - S(X_t))I_t\,;\;\; S',\, S'' \geq 0\,;\;\; S(1) = S'(1) = 0 \tag{32}$$

where $X_t \equiv \frac{I_t}{I_{t-1}}$. This captures the ideas that adjustment costs are associated with *changes* rather than *levels* of investment.[6] Gross investment consists of domestic and foreign final goods

$$I_t = \left[\mathrm{w}_I^{\frac{1}{\rho_I}} I_{H,t}^{\frac{\rho_I - 1}{\rho_I}} + (1-\mathrm{w}_I)^{\frac{1}{\rho_I}} I_{F,t}^{\frac{\rho_I - 1}{\rho_I}} \right]^{\frac{\rho_I}{1-\rho_I}} \tag{33}$$

where weights in investment are defined as in the consumption baskets, namely

$$\mathrm{w}_I \;\; = \;\; 1 - (1-n)(1-\omega_I)\,; \quad \mathrm{w}_I^* = 1 - n(1-\omega_I^*) \tag{34}$$

with investment price given by

$$P_{I,t} = \left[\mathrm{w}_I (P_{H,t})^{1-\rho_I} + (1-\mathrm{w}_I)(P_{F,t})^{1-\rho_I} \right]^{\frac{1}{1-\rho_I}} \tag{35}$$

Capital producers choose the optimal combination of domestic and foreign inputs according to the same form of intra-temporal first-order conditions as for consumption:

$$I_{H,t} = \mathrm{w}_I \left(\frac{P_{H,t}}{P_{I,t}} \right)^{-\rho_I} I_t\,;\;\; I_{F,t} = (1-\mathrm{w}_I) \left(\frac{P_{F,t}}{P_{I,t}} \right)^{-\rho_I} I_t \tag{36}$$

The capital producing firm at time 0 then maximizes expected discounted profits[7]

$$E_t \sum_{t=0}^{\infty} D_{0,t} \left[Q_t (1 - S(X_t)) I_t - \frac{P_{I,t} I_t}{P_t} \right]$$

which, with $X_t \equiv \frac{I_t}{I_{t-1}}$, results in the first-order condition

$$Q_t (1 - S(X_t) - X_t S'(X_t)) + E_t \left[\frac{1}{(1+R_{t+1})} Q_{t+1} S'(X_t) \frac{I_{t+1}^2}{I_t^2} \right] = \frac{P_{I,t}}{P_t} \tag{37}$$

[6] In a balanced growth steady state adjustment costs are associated with change relative to trend so that the conditions on $S(\cdot)$ along the balanced growth path become $S(1+g) = S'(1+g) = 0$.

[7] This ignores leasing costs which Gertler *et al.* (2003) show to be of second order importance.

2.3 The Equilibrium, Fiscal Policy and Foreign Asset Accumulation

In equilibrium, goods markets, money markets and the bond market all clear. Equating the supply and demand of the home consumer good and assuming that government expenditure, taken as exogenous, goes exclusively on home goods we obtain[8]

$$Y_t = C_{H,t} + C^e_{H,t} + I_{H,t} + \frac{1-\nu}{\nu}\left[C^*_{H,t} + C^{e*}_{H,t} + I^*_{H,t}\right] + G_t \tag{38}$$

Fiscal policy is rudimentary: a balanced government budget constraint given by

$$P_{H,t}G_t = T_t + M_{H,t} - M_{H,t-1} \tag{39}$$

Adjustments to the taxes, T_t, in response to shocks to government spending away from the steady state are assumed to be non-distortionary.

Let $\sum_{h=1}^{\nu} B_{F,t}(h) = \nu B_{F,t}$ are the net holdings by the household sector of foreign bonds. Summing over the household budget constraints (including entrepreneurs), noting that net holdings of domestic bonds are zero (since home bonds are not held by foreign households) and subtracting (39), we arrive at the accumulation of net foreign assets:

$$\begin{aligned} P^*_{B,t}S_tB_{F,t} + S_tM_{F,t} &= S_tB_{F,t-1} + S_tM_{F,t-1} + W_tL_t + \Gamma_t + (1-\xi_e)P_tV_t \\ &- P_tC_t - P_tC^e_t - P_{I,t}I_t - P_{H,t}G_t \\ &\equiv S_tB_{F,t-1} + S_tM_{F,t-1} + TB_t \end{aligned} \tag{40}$$

where the trade balance, TB_t, is given by the national accounting identity

$$P_{H,t}Y_t = P_tC_t + P_tC^e_t + P_{I,t}I_t + P_{H,t}G_t + TB_t \tag{41}$$

This completes the model. Given nominal interest rates $R_{n,t}, R^*_{n,t}$ the money supply is fixed by the central banks to accommodate money demand. By Walras' Law we can dispense with the bond market equilibrium condition. Then the equilibrium is defined at $t = 0$ as stochastic sequences C_t, C^e_t, $C_{H,t}$, $C_{F,t}$, $P_{H,t}$, $P_{F,t}$, P_t, $M_{H,t}$, $M_{F,t}$, $B_{H,t}$, $B_{F,t}$, W_t, Y_t, L_t, $P^0_{H,t}$, P^I_t, K_t, I_t, Q_t, V_t, foreign counterparts C^*_t, etc, RER_t, and S_t, given the monetary instruments $R_{n,t}$, $R^*_{n,t}$ and exogenous processes.

2.4 Specialization of The Household's Utility Function

The choice of utility function must achieve two objectives. The first, as in Felices and Tuesta (2006), is to provide a channel by which dollarization affects the marginal utility of consumption. This is achieved by a utility function which is non-separable in consumption

[8]Note that all aggregates, Y_t, $C_{H,t}$, etc are expressed in per capita (household) terms.

and money balances. The second objective is to have a model consistent with the balanced growth path (henceforth BGP) set out in previous sections. As pointed out in Barro and Sala-i-Martin (2004), chapter 9, this requires a careful choice of the form of the utility as a function of consumption and labour effort. Again, as in Gertler *et al.* (2003), it is achieved by a utility function which is non-separable, this time in the latter two arguments.

A utility function of the form

$$U \equiv \frac{(\varepsilon_t + 1)\left[\Phi(h)^{1-\varrho}(1 - L_t(h)(1 - \varepsilon_{L,t}))^{\varrho}\right]^{1-\sigma}}{1-\sigma} \tag{42}$$

where

$$\Phi_t(h) \equiv \left[b(C_t(h) - h_C C_{t-1})^{\frac{\theta-1}{\theta}} + (1-b)Z_t(h)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}} \tag{43}$$

$$Z_t(h) \equiv \left[a\left(\frac{(\varepsilon_{M_H,t}+1)M_{H,t}(h)}{P_t}\right)^{\frac{\chi_M-1}{\chi_M}} + (1-a)\left(\frac{(\varepsilon_{M_{F,t}}+1)S_t M_{F,t}(h)}{P_t}\right)^{\frac{\chi_M-1}{\chi_M}}\right]^{\frac{\chi_M}{\chi_M-1}} \tag{44}$$

and where labour supply, $L_t(h)$, is measured as a proportion of a day, normalized at unity, satisfies these two requirements.[9] For this function, $U_{\Phi L} > 0$ so that consumption and money holdings together, and leisure (equal to $1 - L_t(h)$) are substitutes.

2.5 State Space Representation

We linearize around a deterministic zero-inflation, balanced growth steady state. We can write the two-bloc model in state space form as

$$\begin{aligned}\begin{bmatrix} \mathsf{z}_{t+1} \\ E_t\mathsf{x}_{t+1} \end{bmatrix} &= A\begin{bmatrix} \mathsf{z}_t \\ \mathsf{x}_t \end{bmatrix} + B\mathsf{o}_t + C\begin{bmatrix} r_{n,t} \\ r^*_{n,t} \end{bmatrix} + D\mathsf{v}_{t+1} \\ \mathsf{o_t} &= H\begin{bmatrix} \mathsf{z}_t \\ \mathsf{x}_t \end{bmatrix} + J\begin{bmatrix} r_{n,t} \\ r^*_{n,t} \end{bmatrix}\end{aligned} \tag{45}$$

where z_t is a vector of predetermined exogenous variables, x_t are non-predetermined variables, and o_t is a vector of outputs.[10] Matrices A, B, etc are functions of model parameters. Rational expectations are formed assuming an information set $\{z_{1,s}, z_{2,s}, x_s\}$, $s \leq t$, the model and the monetary rule. Details of the linearization are provided in Appendix B.

[9] A BGP requires that the real wage, real money balances and consumption grow at the same rate at the steady state with labour supply steady. It is straightforward to show that (42) has these properties.

[10] We define all lower case variables as proportional deviations from this baseline steady state except for rates of change which are absolute deviations. That is, for a typical variable X_t, $x_t = \frac{X_t - X}{X} \simeq \log\left(\frac{X_t}{X}\right)$ where X is the baseline steady state. For variables expressing a rate of change over time such as the nominal interest rate $r_{n,t}$ and inflation rates, $x_t = X_t - X$.

2.6 The Small Open Economy

Following Felices and Tuesta (2006), we can now model a small open economy by letting its relative size in the world economy $n \to 0$ whilst retaining its linkages with the rest of the world (ROW). In particular the demand for exports is modelled in a consistent way that retains its dependence on shocks to the home and ROW economies. We now need a fully articulated model of the ROW. From (6) we have that $\mathrm{w} \to \omega$ and $\mathrm{w}^* \to 1$ as $n \to 0$. Similarly for investment we have $\mathrm{w}_I \to \omega_I$ and $\mathrm{w}_I^* \to 1$ as $n \to 0$. It seems at first glance then that the ROW becomes closed and therefore exports from our small open economy must be zero. However this is not the case. Consider the linearized form of the output demand equations in the two blocs:

$$\begin{aligned} y_t &= \alpha_{C,H} c_t + \alpha^e_{C,H} c^e_t + \alpha^*_{C,H} c^*_t + \alpha_{I,H} i_t + \alpha^*_{I,H} i^*_t + \alpha_G g_t \\ &+ [\mu(\alpha_{C,H} + \alpha^e_{C,H})(1-\mathrm{w}) + \mu^* \alpha^*_{C,H} \mathrm{w}^* + \rho_I \alpha_{I,H}(1-\mathrm{w}_I) + \rho^*_I \alpha^*_{I,H} \mathrm{w}^*_I]\tau_t \quad (46) \\ y^*_t &= \alpha^*_{C,F} c^*_t + \alpha_{C,F} c_t + \alpha^e_{C,F} c^e_t + \alpha^*_{I,F} i^*_t + \alpha_{I,F} i_t + \alpha^*_G g^*_t \\ &- [\mu^*(\alpha^*_{C,F}(1-\mathrm{w}^*) + \mu \alpha_{C,F} \mathrm{w} + \rho^*_I \alpha^*_{I,F}(1-\mathrm{w}^*_I) + \rho_I \alpha_{I,F} \mathrm{w}_I]\tau_t \quad (47) \end{aligned}$$

where the elasticities and their limits as $n \to 0$ are given by

$$\begin{aligned} \alpha_{C,H} &= \frac{\mathrm{w}(1-s_e)C}{Y} \to \frac{\omega(1-s_e)C}{Y} \\ \alpha^e_{C,H} &= \frac{\mathrm{w} s_e C}{Y} \to \frac{\omega s_e C}{Y} \\ \alpha^*_{C,H} &= \frac{(1-\mathrm{w}^*)C^*}{Y^*} \frac{(1-n)Y^*}{nY} \to \frac{(1-\omega^*)C^*}{Y^*} \frac{Y^*}{Y} \\ \alpha_G &= \frac{G}{Y} \\ \alpha_{I,H} &= \frac{\mathrm{w}_I I}{Y} \to \frac{\omega_I I}{Y} \\ \alpha^*_{I,H} &= \frac{(1-\mathrm{w}^*_I)I^*}{Y^*} \frac{(1-n)Y^*}{nY} \to \frac{(1-\omega^*_I)I^*}{Y^*} \frac{Y^*}{Y} \\ \alpha^*_{C,F} &= \frac{\mathrm{w}^* C^*}{Y^*} \to \frac{C^*}{Y^*} \\ \alpha^{e*}_{C,F} &= 0 \\ \alpha_{C,F} &= \frac{(1-\mathrm{w})C}{Y} \frac{nY}{(1-n)Y^*} \to 0 \\ \alpha^e_{C,F} &= \frac{(1-\mathrm{w})(1-\xi^e)n_k k_y}{\xi_e} \frac{nY}{(1-n)Y^*} \to 0 \\ \alpha^*_G &= \frac{G^*}{Y^*} \\ \alpha^*_{I,F} &= \frac{\mathrm{w}^*_I I^*}{Y^*} \to \frac{I^*}{Y^*} \\ \alpha_{I,F} &= \frac{(1-\mathrm{w}_I)I}{Y^*} \frac{nY}{(1-n)Y^*} \to 0 \end{aligned}$$

Thus we see that from the viewpoint of the ROW our small open economy becomes invisible, but not vice versa. Exports to and imports from the ROW are now modelled explicitly in a way that captures all the interactions between shocks in the ROW and the transmission to the small open economy.

2.7 Calibration

2.7.1 Home Bias Parameters

The bias parameters we need to calibrate are: ω, ω^*, ω_I and ω_I^*. Let in the steady state $C^e = s_e C$ be consumption by entrepreneurs, and $c_y = \frac{C}{Y}$. Let $cs_{imports}$ be the GDP share of imported consumption of the foreign (F) consumption good. Let $cs_{exports}$ be the GDP share of exports of the home (H) consumption good. Then we have that

$$\begin{aligned}
\alpha_{C,H} &= \frac{C_H}{Y} = \frac{\omega C}{Y} = (c_y - cs_{imports})(1 - s_e) \\
\alpha^e_{C,H} &= \frac{C_H{}^e}{Y} = \frac{\omega C^e}{Y} = (c_y - cs_{imports})s_e \\
\alpha^*_{C,H} &= \frac{C^*_H}{Y} = \frac{(1-\omega^*)C^*}{Y^*}\frac{Y^*}{Y} = cs_{exports}
\end{aligned}$$

Similarly for investment define $is_{imports}$ to be the GDP share of imported investment of the F investment and $is_{exports}$ be the GDP share of exports of H investment good. Then with $i_y = \frac{I}{Y}$, we have

$$\begin{aligned}
\alpha_{I,H} &= \frac{I_H}{Y} = \frac{\omega_I I}{Y} = i_y - is_{imports} \\
\alpha^*_{I,H} &= \frac{I^*_H}{Y} = \frac{(1-\omega^*_I)I^*}{Y^*}\,\frac{Y^*}{Y} = is_{exports}
\end{aligned}$$

in the steady state. We linearize around a zero trade balance $TB = 0$, so we require

$$cs_{imports} + is_{imports} = cs_{exports} + is_{exports} \tag{48}$$

in which case $\alpha_{C,H} + \alpha^e_{C,H} + \alpha^*_{C,H} + \alpha_{I,H} + \alpha^*_{I,H} = c_y + i_y$ as required. Thus we can use trade data for consumption and investment goods, consumption shares and relative per capita GDP to calibrate the bias parameters ω, ω^*, ω_I and ω_I^*. We need the home country biases elsewhere in the model, but for the ROW we simply put $\omega^* = \omega_I^* = 1$ everywhere else, so these biases are not required as such.

2.7.2 Calibration of Household Preference Parameters

We now show how observed data on the household wage bill as a proportion of total consumption, real money balances as a proportion of consumption and estimates of the

elasticity of the marginal utility of consumption with respect to total money balances can be used to calibrate the preference parameters ϱ, b and θ in (42).

Calibrating parameters to the BG steady state, we first note that from (16) we have

$$\frac{(\eta-1)}{\eta}\frac{W(1-L)}{PC}=\frac{\varrho\Phi}{C(1-h_C)\Phi_C(1-\varrho)} \tag{49}$$

In (49), $\frac{W(1-L)}{PC}$ is the household wage bill as a proportion of total consumption, which is observable. From the definition of Φ in (43), we have that

$$\frac{\Phi}{C\Phi_C}=\frac{(1-b)cz^{\frac{1-\theta}{\theta}}+b}{b} \tag{50}$$

where $cz\equiv\frac{C(1-h_C)}{Z}$ is the 'effective-consumption' –real money balance ratio (allowing for external habit). From (42), the elasticity the marginal utility of consumption with respect to total money balances, Ψ say is given by

$$\frac{ZU_{CZ}}{U_C}\equiv\Psi=\frac{(1-b)[(1-\varrho)(1-\sigma)-1+\frac{1}{\theta}}{bcz^{\frac{\theta-1}{\theta}}+1-b} \tag{51}$$

From the first-order conditions in the steady state (A.26) and (A.27) with $R_n=R_n^*=R$ we have

$$\frac{b(1-h_C)}{1-b}\,cz^{-\frac{1}{\theta}}=\frac{1+R}{R} \tag{52}$$

Thus given σ, β, g, h_C, $\frac{W(1-L)}{PC}$, cz and Ψ, equations (49)–(52) can be solved for ϱ, b and θ. Figure 1 shows calculations for these parameters for the calibrated values of σ, β, g, h_C, $\frac{W(1-L)}{PC}$ and cz set out in Appendix C for a plausible range[11] of $\Psi\in[0,0.01]$. Since $\Psi>0$ we impose on our calibration the property that money and consumption are *complements*.

2.7.3 Remaining Parameters

As far as possible parameters are chosen based on quarterly data for Peru. Elsewhere the parameters reflect broad characteristics of emerging economies. A variety of sources are used: for Peru we draw upon Castillo *et al.* (2006) (CMT). For emerging economies more generally and for parameters related to the financial accelerator we use Gertler *et al.* (2003) (GGN) and Bernanke *et al.* (1999) (BGG). The rest of the world is represented by US data. Here we draw upon Levin *et al.* (2006) (LOWW). In places we match Peru with European estimates using Smets and Wouters (2003) (SW). Appendix C provides full details of the calibration.

[11] See Woodford (2003), chapter 2 for a discussion of this parameter.

3 Monetary Policy Interest Rate Rules

In line with the literature on open-economy interest rate rules (see, for example, Benigno and Benigno (2004)), we assume that the central bank in the emerging market bloc has three options : (i) set the nominal interest to keep the exchange rate fixed (fixed exchange rates, 'FIX'); (ii) set the interest rate to minimize deviations of domestic or CPI inflation from a predetermined target (inflation targeting under fully flexible exchange rates, 'FLEX(D)' or 'FLEX(C)'); or, finally (iii) follow a hybrid regime, in which the nominal interest rates responds to both inflation deviations from target and exchange rate deviations from a certain level (managed float, 'HYB'). Many emerging market countries follow one or another of these options and most are likely to in the near future. Formally, the rules are:

Fixed Exchange Rate Regime, 'FIX'. In a simplified model without an exchange rate premium analyzed in section 4 we show this is implemented by

$$r_{n,t} = r^*_{n,t} + \theta_s s_t \tag{53}$$

where any $\theta_s > 0$ is sufficient to the regime. In our full model with an exchange rate premium, we implement 'FIX' as a 'HYB' regime below, with feedback coefficients chosen to minimize a loss function that includes a large penalty on exchange rate variability. (Note that values for the loss function reported below remove the latter contribution).

Inflation Targets under a Fully Flexible Exchange Rate, 'FLEX(D)' or 'FLEX(C)'. This takes the form of Taylor rule with domestic or CPI inflation and output growth targets:

$$r_{n,t} = \rho r_{n,t-1} + \theta_\pi E_t \pi_{H,t} + \theta_y \Delta y_t \tag{54}$$

$$r_{n,t} = \rho r_{n,t-1} + \theta_\pi E_t \pi_t + \theta_y \Delta y_t \tag{55}$$

where $\rho \in [0, 1]$ is an interest rate smoothing parameter.

Managed Float, 'HYB'. In this rule the exchange rate response is direct rather than indirect as in the CPI inflation rule, (55):[12]

$$r_{n,t} = \rho r_{n,t-1} + \theta_\pi E_t \pi_{H,t} + \theta_y \Delta y_t + \theta_s s_t \tag{56}$$

[12]Rule (56) describes one of many possible specifications of a managed float, namely one where the central bank resists deviations of the exchange rate from a certain level–considered to be the equilibrium– as well as deviations of inflation from target and output from potential. An equally plausible specification involves a feedback on the rate of change of the exchange rate, in which case the central bank aim is to stabilize exchange rate volatility, i.e. the pace at which the domestic currency appreciates or depreciates over time. For a discussion see Batini *et al.* (2003). To limit the number of simulations and results to be compared, here we limit ourselves to one specification only.

In all cases we assume that the central bank in the emerging market bloc enjoys full credibility. Although this assumption may have been considered heroic a few years ago, today there are several emerging market countries that have succeeded in stabilizing inflation at low levels and have won the trust of , including economies with a history of high or hyper-inflation (e.g. Brazil, Israel, Peru and Mexico, among others. See Batini *et al.* (2006). Accounting for imperfect credibility of the central bank remains nonetheless important for many other emerging market countries, and can lead to higher stabilization costs than under full credibility (under inflation targeting and floating exchange rate, see Aoki and Kimura (2007) or even sudden stops and financial crises (under fixed exchange rates, see IMF (2005)).

4 Transactions Dollarization in a Model without Capital

The stability and determinacy properties of various monetary rules provide a good indication of their stabilization performance. However, the full model with capital, the financial accelerator and both transactions and liability dollarization has high-order dynamics and is not analytically tractable. In order to throw some light on the numerical results that follow, in this section we therefore study a special case of the model which suppresses capital, the associated financial accelerator, habit in consumption and the exchange rate risk premium facing households (i.e., $h_C = \delta_r = 0$). The analysis provides results on the consequences of transactions dollarization for a simple current domestic inflation targeting rule in the form (54) with $\theta_y = 0$.

We are interested in establishing the conditions for this current domestic inflation rule to be saddle-path stable. Exogenous processes play no part in this property (so long as they themselves are stable or saddle-path stable, a property we assume). Ignoring these processes we can express the linearized system in terms of the marginal utilities of consumption, $u_{c,t}$ in deviation form,[13] and the marginal disutility of labour ($u_{l,t}$) which holds for any choice of utility function. After some effort this takes the form

$$E_t u_{c,t+1} = u_{c,t} - \omega(r_{n,t} - E_t \pi_{H,t+1}) \tag{57}$$

$$\beta E_t \pi_{H,t+1} = \pi_{H,t} - \lambda_H \left(u_{l,t} - \frac{1}{\omega} u_{c,t} \right) \tag{58}$$

$$y_t = l_t = \alpha_{C,H} c_t - \nu u_{c,t} \tag{59}$$

[13] Recall that all lower case variables are proportional deviations from the steady state, except for rates of change which are absolute deviations. See footnote 12.

where $\lambda_H = \frac{(1-\beta\xi_H)(1-\xi_H)}{\xi_H}$ and $\nu = \frac{1}{\omega}(\mu\alpha_{C,H}(1-\omega)+\mu^*\alpha^*_{C,H})$. After further algebra, using the expressions for $u_{c,t},\ u_{l,t},\ y_t,\ c_t$ in Appendix B, we arrive at the following specification for $\pi_{H,t}$ expressed solely in terms of $u_{c,t}$ and $r_{n,t}$:

$$\beta E_t \pi_{H,t+1} = \pi_{H,t} + \gamma u_{c,t} - \kappa r_{n,t} \tag{60}$$

where

$$\gamma = \lambda_H \left(\frac{L}{1-L}\frac{1-\omega}{\omega} + \frac{L}{1-L}\nu + \frac{(1+\frac{L}{1-L}\omega c_y)(1+\nu)\frac{\rho(\sigma-1)L}{1-L}}{1+(\sigma-1)(1-\rho)-\rho(\sigma-1)\omega c_y \frac{L}{1-L}} \right)$$

$$\kappa = \bar{a}\lambda_H \varpi_L + \frac{\bar{a}\lambda_H(1+\frac{L}{1-L}\omega c_y)\varpi}{1+(\sigma-1)(1-\rho)-\rho(\sigma-1)\omega c_y \frac{L}{1-L}}$$

and ϖ, ϖ_L, b_1, $\bar{a}$ and α are defined in Appendix B.

We restrict ourselves to a range of parameter values for which $\sigma > 1$ and $(1-\rho) - \rho\omega c_y \frac{L}{1-L} > 0$. Since $\omega c_y \frac{L}{1-L} \ll 1$ this is a very weak condition that our calibrated values easily satisfy. Then $\gamma > 0$. Furthermore κ can be either positive or negative. By definition ϖ_L, the elasticity of the marginal utility of work effort with respect to the nominal interest rate is always positive. But the sign of ϖ, the corresponding elasticity of the marginal utility of consumption, depends on whether consumption and real balances are substitutes or complements. If they are substitutes then $\varpi > 0$ and then $\kappa > 0$. But here we assume that they are complements, in which case κ can take either sign. Our results below are sensitive to this.

In fact for our chosen calibration κ is comfortably positive. This means that the nominal interest rate impacts on the economy through two channels. First, given expectations of CPI inflation, an increase in the nominal interest rate reduces the expected real interest rate and reduces demand from consumption. This will cause the domestic inflation rate to fall in the usual way. But with a non-separable utility function, there is a second channel of influence through the supply-side that sees marginal cost, and therefore the inflation rate, rise as the result of an increase in the interest rate. Thus with $\kappa > 0$ *supply and demand effects work in opposite directions and the supply side effect will tend to undermine the stabilizing demand side effect.* However κ depends on the degree of transactions dollarization. $\kappa = 0$ when there is complete dollarization $a = \bar{a} = 0$ and therefore the supply effect closes down. This eliminates a destabilizing effect, so as we approach complete transactions dollarization we will should witness a more effective form of monetary stabilization.

Equations (57) and (60) form the basis for the analysis of the next section. The important feature of the modified Phillips curve, (60) with a non-separable utility function

in money and consumption is the manner in which the domestic interest rate impacts on domestic inflation.

4.1 Fixed Exchange Rate Regime ('FIX')

For the model without capital and an exchange rate risk premium, the saddle-path stability of the FIX regime is unambiguous as the following proposition indicates:

Proposition 1

Under regime '**FIX**':

(a) The system is stable and determinate for all values of $\theta_s > 0$.

(b) The nominal exchange rate is fixed.

Proof: see Appendix D.

As Benigno and Benigno (2004) have stressed, the feedback from the exchange rate to the interest rate is not operative in the equilibrium because $s_t = 0$ at all times. Rather it is the *belief* that the monetary authority responds in this way even for very small θ_s that maintains a fixed exchange rate. With such a regime the domestic interest rate that enters the Phillips curve in (60) remains fixed too, so neither the non-separable form of the utility function, nor the existence of dollarization has an impact on the stability properties of the system.

4.2 Domestic Inflation Targeting Rule ('FLEX (D)')

Now consider the rule (54). In the rest of this section we focus on inflation-targeting interest rate rules that respond only to domestic inflation, but not to output growth. This makes the analysis tractable but there are other reasons for examining such rules. First, pure inflation-targeting or inflation-targeting with a managed exchange rate corresponds to the objectives of many modern central banks. Second, it is of intrinsic interest to see to what extent an economy can be stabilized with the simplest possible form of rule that only tracks one nominal variable. With this form of rule we can then show:

Proposition 2

Under '**FLEX(D)**':

(a) If $2\kappa > \omega\gamma > (1-\rho)\kappa$, then the system is stable and determinate for the range $1 < \theta_\pi < \frac{(1+\rho)(2(1+\beta)+\gamma\omega}{(1-\rho)(2\kappa-\gamma\omega)} \triangleq \bar{\theta}_\pi$.

(b) If $\omega\gamma > 2\kappa$, then any feedback $\theta_\pi > 1$ from current inflation leads to stability and determinacy.

Proof: See Appendix D. An immediate corollary follows:

Corollary 1

As $\rho \to 1$ and we approach an integral rule, then the range $[1, \bar{\theta}_\pi]$ in (a) becomes infinite.

Thus interest rate smoothing helps to induce determinacy a result obtained in Batini *et al.* (2004) for both current and forward-looking inflation targeting rules. Furthermore we show in Appendix D that κ decreases with increasing dollarization in the range $0 < a < \frac{1}{2}$ which leads to another corollary:

Corollary 2

For high levels of dollarizarion $a < \frac{1}{2}$, as dollarization increases further, then κ falls and the determinacy range for θ_π increases.

Thus for a current domestic inflation rule, a high degree of transactions dollarization poses no problems for stability and determinacy, in fact, helps to avoid the both problems. The intuition behind this result is that with $\kappa > 0$, a case easily supported by the calibration, supply and demand effects of nominal interest rate changes operate in opposite directions. But transactions dollarization closes down the supply-side effect and therefore helps the stabilization process.

Figure 2 illustrates our result using our central calibration. We see that condition (a) is just satisfied for all degrees of transactions dollarization, $a \in [0, 1]$ if $\rho > 0.25$ which is a very modest degree of interest rate smoothing. These results have been obtained for a simple model where many of the features in our full model have been suppressed. Nevertheless they are suggestive of the effects of transactions dollarization on the stabilization properties of a simple current domestic inflation rule in the full model.

5 Optimal Monetary Policy, Volatility and Impulse Responses

How do financial frictions and dollarization in emerging market economies affect the transmission mechanism of monetary policy and the volatilities of output, inflation and other key variables? To answer this question we do two things. First, we parameterize four representations of the model with increasing frictions and dollarization, and solve them subject to the corresponding optimal monetary policy rule based on maximizing the household's utility. (Later, in section 6, this provides a benchmark against which to assess the welfare implications of the fixed-exchange rate regime and various Taylor-type flexible exchange rate rules.) We then compare the volatilities delivered by each model for key macro-variables, including inflation and output. Second, we analyze how transmission of shocks is affected by frictions and dollarization, by tracing impulse responses to two key

shocks.

5.1 Optimal Monetary Policy and Volatilities

We adopt a linear-quadratic framework for the optimization problem facing the monetary authority. This is particularly convenient as we can then summarize outcomes in terms of unconditional (asymptotic) variances of macroeconomic variables and the local stability and determinacy of particular rules. The framework also proves useful for addressing the issue of the zero lower bound on the nominal interest rate.

Following Woodford (2003), we adopt a 'small distortions' quadratic approximation to the household's single period utility which is accurate as long as the zero-inflation steady state is close to the social optimum. There are three distortions that result in the steady state output being below the social optimum: namely, output and labour market distortions from monopolistic competition and distortionary taxes required to pay for government-provided services. Given our calibration these features would make our distortions far from small. However there is a further distortion, external habit in consumption, that in itself raises the equilibrium steady state output above the social optimum. If the habit parameter h_C is large enough the two sets of effects can cancel out and thus justify our small distortions approximation. In fact this is the case in our calibration.[14]

From Appendix E our quadratic approximation to the household's intertemporal expected loss function is given by

$$\Omega_0 = E_t\left[(1-\beta)\sum_{t=0}^{\infty}\beta^t L_t\right] \tag{61}$$

where

$$\begin{aligned}
2L_t &= w_c\left(\frac{c_t - h_C c_{t-1}}{1-h_C}\right)^2 + w_\tau \tau_t^2 + w_{cl}\left(\frac{c_t - h_C c_{t-1}}{1-h_C}\right) l_t + w_l l_t^2 \\
&+ w_k(k_{t-1} - l_t)^2 - w_{ay} y_t a_t + w_{ci\tau} ci_t \tau_t + w_{cls\tau} cls_t \tau_t + w_\pi \pi_{H,t}^2 \qquad (62)\\
ci_t &\equiv \mu\omega(1-\omega)c_y c_t + \mu(1-\omega^*)c_y c_t^* + \rho_I \omega_I (1-\omega_I) i_y i_t + \rho_I^*(1-\omega_I^*) i_y i_t^* \\
cls_t &\equiv [(1-\sigma)(1-\varrho)-1]\frac{c_t^* - h c_{t-1}^*}{1-h} - (1-\sigma)\varrho\frac{L^* l_t^*}{1-L^*}
\end{aligned}$$

and the weights w_c, w_τ, etc are defined in Appendix E. Thus from (62) welfare is reduced as a result of volatility in consumption adjusted to external habit, $c_t - h_C c_{t-1}$; the terms of trade, τ_t, labour supply l_t, domestic inflation $\pi_{H,t}$ and foreign shocks. There are also some covariances that arise from the procedure for the quadratic approximation of the loss

[14] See Levine *et al.* (2007) and Levine *et al.* (2006) for a discussion of these issues. The former paper provides details of all the optimization procedures in this paper.

function. The policymaker's problem at time $t = 0$ is then to minimize (61) subject to the model in linear state-space form given by (45), initial conditions on predetermined variables z_0 and the Taylor rule followed by the ROW. Details of the optimization procedure are provided in Levine *et al.* (2007).

We parameterize the model according to four alternatives, ordered by increasing degrees of frictions and dollarization:

- (Model I) no transaction dollarization, no financial accelerator and no liability dollarization. This is a fairly standard small open-economy model similar to many in the New Keynesian open-economy literature with the only non-standard features being a non-separable utility function in money balances, consumption, and leisure consistent with a balanced growth path and a fully articulated ROW bloc;

- (Model II) transaction dollarization (TD) only (where the degree of TD is captured by $1 - a$ where $a \in [0, 1]$;

- (Model III) financial accelerator (FA) only;

- (Model IV) financial accelerator (FA) and liability dollarization (LD), assuming that firms borrow a fraction of their financing requirements $1 - \varphi \in [0, 1]$ in dollars;

- (Model V) TD plus FA plus LD, where $a = \varphi = 0.5$, i.e. medium level TD and LD.

We subject all these variants of the model to six exogenous and independent shocks. Three of these, total factor productivity (a_t), government spending (g_t) and the external risk premium facing firms, $\epsilon_{P,t}$ are domestic and three, a foreign demand counterpart to g_t^*, a country risk premium shock to the modified UIP condition, $\epsilon_{UIP,t}$ and and shock to the foreign interest rate rule $\epsilon_{R,t}^*$ originate from the ROW. The foreign bloc is fully articulated, so the effect of these shocks impacts on the domestic economy through changes in the demand for exports, though since the domestic economy is small, there is no corresponding effect of domestic shocks on the ROW. [15]

The first question we pose is what is the relative importance of these six shocks for the welfare of domestic households under optimal monetary policy? Table 1 provides the answer by carrying out an expected welfare decomposition[16] with respect to the shocks for our four model variants. For both TD and LD we assume a degree of dollarization $1 - a = 1 - \varphi = 0.5$. Given our calibration the most important shock is that to technology

[15] Of course, the simulation results reported below depend on our calibration of both structural parameters and shocks, particularly on the parameters determining the exchange rate elasticity of trade and net worth. However, changing these with a plausible range does not affect the results qualitatively.

[16] The expected welfare loss is the conditional loss in the vicinity of the steady state.

irrespective of the existence of a FA or LD. But as these latter features are introduced in turn, the model economy becomes increasing vulnerable to the three foreign shocks with the contribution of technology falling from 82% in model I to 44% in model IV. Our earlier analysis of a model without capital suggested that TD improve stabilization and Table 1 confirms this for the full model– indeed TD sees a reduction in the welfare loss emanating from all shocks.

Figure 3 picks out some key variables and shows standard deviations associated with model I, model II with medium and high degrees of TD (IIM, IIH) model III and model IV with low, medium and high degrees of TD (IVL, IVM, IVH) under optimal policy.[17] Table 2 presents volatility results for all model variables. This broadly reaffirms the general result that more frictions and liability dollarization trigger greater economic volatility. Investment, net worth, interest rate and real exchange variability are particularly high for even moderate degrees of liability dollarization and financial acceleration, compared to a world without such features.

A number of further features of these volatilities deserve highlighting. First consider TD proceeding from the baseline model with no TD to the opposite extreme of full TD. As mentioned previously welfare does not deteriorate but indeed increases and this is confirmed by the reduction in variances of consumption, the terms of trade (implied by the lower variance of the real exchange rate) and inflation which feature in the loss function. However this comes at a cost of an increase in the variance of the nominal interest rate since TD closes down one channel for monetary intervention. This higher interest rate has implications in terms of the zero lower bound (ZLB) constraint, an issue we return to in section 7.

Now consider the FA and LD. With the emergence of the FA we see an increase in the variances of all variables which is marked in the case of output and investment. Variances increase further at first, as LD is introduced, but for complete LD, investment and net worth volatility are lower. We explore this phenomenon below in our discussion of impulse response functions. The combination of the FA and LD is a lethal cocktail for the welfare of households. Welfare loss increases sharply for high levels of LD with $\varphi > 0.5$. The variance of the nominal interest rate also increases substantially with further implications for welfare when we impose the ZLB.

To summarize these results:

- Inflation, consumption and output volatility worsen markedly as financial frictions in the form of the FA, and eventually LD, are introduced. However TD, even when complete, does not worsen volatility except for the nominal interest rate.

[17] We do not show Model V because adding TD has no visible implications for volatilities in the chart

- Full liability dollarization combined with the financial accelerator leads to levels real and nominal volatility that are several times larger than those present in an economy without such features, for the same shocks. As a result the expected welfare loss increases sharply for high levels of LD with $\varphi < 0.5$.

- The central bank is more aggressive in its use of the nominal interest rate with both forms of dollarization. As a result, the variance of the nominal interest rate increases and markedly so for LD. This has important further implications for welfare when we impose the interest rate zero lower bound.

How do these volatilities match up to data on financially dollarized economies? Probably the most definitive and wide-ranging work on empirical issues on dollarization is due to Levy Yeyati (2006), who analyses a unique database. His cross-sectional time series data reveals a positive correlation between dollarization and the standard deviation of growth rates, which is a feature of the last penultimate row of Table 2. Without liability dollarization, devaluations lead to countercyclical behaviour and eventually restore the economy to equilibrium. In the presence of LD, the balance sheet effect ultimately leads to lower borrowing and capital formation, and lower growth on average coupled with increased variability.[18]

5.2 Assessing the Impact of Key External and Internal Shocks

In this section we study impulse responses for two selected shocks which our earlier results have shown have important welfare implications: a technology shock (a_t) and a shock to the country's external risk premium, $\epsilon_{UIP,t}$. These are shown in figures 4–7, which concentrate on the baseline model (no frictions/dollarization) and model variants where dollarization/frictions are most pernicious (Models III and IVH). Although the analysis looks similar to Gilchrist (2003), it is in fact quite distinct in that here we are interested in comparing the transmission of shocks as frictions and dollarization increase, rather than in comparing the performance of flexible versus fixed exchange rates *given* frictions and liability dollarization.

To understand how the transmission of the shock changes for different levels of frictions and dollarization, we need first to take a step back and illustrate some of the mechanisms driving the real exchange rate, and the behavior of net worth of the wholesale firms sector.

Movements in the real exchange rate (and the related terms of trade) are critical for understanding our results. Linearization of the modified UIP condition (17) gives

$$rer_t = E_t rer_{t+1} + E_t(r_t^* - r_t) - \delta_r b_{F,t} + \epsilon_{UIP,t} \tag{63}$$

[18] However Levy Yeyati (2006) is unable to pick up the balance sheet effects from the data.

Solving (63) forward in time we see that the real exchange rate is a sum of future expected real interest rate differentials with the ROW plus a term proportional to the sum of future expected net liabilities plus a sum of expected future shocks $\epsilon_{UIP,t}$. The real exchange will depreciate (a rise in rer_t) if the sum of expected future interest rate differentials are positive and/or the sum of expected future net liabilities are positive and/or a positive shock to the risk premium, $\epsilon_{UIP,t}$ occurs.

Also crucial to the understanding of the effects of the FA and LD is the behaviour of the net worth of the wholesale sector. In linearized form this is given by

$$\begin{aligned} n_t &= \frac{\xi_e}{1+g}\Big[\frac{1}{n_k}r^k_{t-1} + (1+\Theta)(1+R)n_{t-1} \\ &+ \left(1-\frac{1}{n_k}\right)\left[(1+R)\theta_{t-1} + (1+\Theta)(\varphi r_{t-1} + (1-\varphi)(r^*_{t-1} + (1+R)(rer_t - rer_{t-1})\right]\Big] \end{aligned} \tag{64}$$

where the ex ante cost of capital is given by r^k_{t-1}. In (64) since leverage $\frac{1}{n_k} > 1$ we can see that net worth increases with the ex post return on capital at the beginning of period t, r^k_{t-1}, and decreases with the risk premium θ_{t-1} charged in period $t-1$ and the the ex post cost of capital in home currency and dollars, $\varphi r_{t-1} + (1-\varphi)(r^*_{t-1} + (1+R)(rer_t - rer_{t-1}))$, noting that $(rer_t - rer_{t-1})$ is the real depreciation of the home currency. Starting at the steady state at $t = 0$, from (64) at $t = 1$ we have

$$n_1 = \frac{\xi_e}{1+g}\left[(1-\delta)q_1 + \left(1-\frac{1}{n_k}\right)(1+\Theta)(1-\varphi)(1+R)rer_1\right] \tag{65}$$

Thus net worth falls if Tobin's Q falls and if some borrowing is in dollars ($\varphi < 1$), we see that a *depreciation* of the real exchange rate ($rer_1 > 0$) brings about a further drop in net worth. However an *appreciation* of the real exchange rate ($rer_1 < 0$) will offset the drop in net worth. Output falls through two channels: first, a drop in Tobin's Q and a subsequent fall in investment demand and, second, through a reduction in consumption by entrepreneurs.

5.2.1 TFP shock

Figures 4 and 5 illustrate the transmission channels in the model under optimal monetary policy in response to a negative 1% shock to total factor productivity. Since TD does not result in big differences in volatilities, we focus on only three variants, the baseline model with no TD nor FA, the model with a FA and the model with both the FA and a high degree of LD. For all three models we have the following broad features: the shocks result in an immediate fall in consumption, output and investment, a tightening of optimal monetary policy with a rise in the nominal and expected real interest rate, an appreciation

of the real exchange rate (rer_t falls), a fall in the terms of trade $\left(p_{F,t} - p_{H,t} = \tau_t = \frac{rer_t}{\omega}\right)$, a trade deficit and a decline in net future assets. Investment falls because Tobin's Q (defined in the graphs as the real market price of capital relative to the price of capital goods, $q_t^k = q_t - p_{I,t} + p_t$), falls which in turn responds to an anticipated future fall in profits relative to the cost of capital. With the FA switched on, the fall in Tobin's Q measured relative to the price of capital relative to the consumption good, q_t, causes net worth to fall which in turn causes the external financing premium facing firms, θ_t, to rise. This exacerbates the increase in the cost of capital and Tobin's Q, and therefore investment, falls further. This is the familiar effect of a FA highlighted, for example, in Gertler *et al.* (2003).

Now consider the FA plus LD where for the graphs we assume all borrowing by firms is in dollars ($\varphi = 0$). In this case, net worth and investment fall by far less, and net worth relative to the value of capital hardly changes as can be seen from movements in the external risk premium. Why is this? The reason is the appreciation of the exchange rate which (from (65) with $\varphi < 1$) offsets the fall in net worth brought about by the fall in Tobin's Q. The policymaker responds to this by tightening more monetary conditions, so that the expected real interest rate rises relative to what happens in a model without LD. *Thus, the presence of LD induces a stronger monetary intervention* particularly in the short run. Another way to explain this is by saying that monetary policy is less effective under LD, other things equal, because the output gap channel of monetary transmission is weaker (since borrowing is partly in dollars, and so the cost of capital is less directly affected by changes in the interest rate), while the exchange rate channel is stronger (because under LD changes in the exchange rate generate balance sheet effects in addition to affecting net trade). As a result the central bank uses the exchange rate more intensely as a stabilizing device, by creating domestic-relative-to-abroad interest rate differentials. For big enough TFP shocks, however, use of the exchange rate channel to minimize 'financial-accelerated' output fluctuations may clash with the objective of keeping inflation within a certain range. As indicated by the figure, it takes much longer for domestic inflation to return to target in a model with FA+LD than in a model without frictions or dollarization.

5.2.2 Country External Risk Premium Shock

Next, in Figure 6 and 7, we turn to a 1% to the domestic country's external risk premium ϵ_{UIPt} in (63). Now the real exchange rate depreciates instead of appreciating as was the case with the technology shock. The responses of all three variants of the model are again broadly similar, implying a drop in output, consumption, investment, a fall in Tobin's Q, a tightening of monetary policy and a fall in net worth. The real depreciation of

the exchange rate leads to a trade surplus and an accumulation of foreign assets. The effect of the FA on net worth, the external risk premium and investment is pretty much the same as for the previous simulations. But when we combine the FA with LD an important difference emerges. Since the real exchange rate now depreciates instead of appreciating, the initial fall in net worth is exacerbated rather than attenuated by balance sheet effects, and the external risk premium rises by more. Monetary policy is tightened by more than in the TFP shock case, so the depreciation is short-lived because the interest rate differential relative to abroad is rapidly closed, and is eventually reversed, turning into an appreciation. With LD, the appreciation that follows the monetary tightening triggers a further balance sheet effect that has the effect of returning net worth back to its steady state faster than in the FA without LD. *Thus, LD has a long-stabilizing effect on movements in net worth.* Given that the external risk premium also returns faster to its equilibrium, forward-looking investment under LD behaves similarly to investment in the baseline, frictionless model. The immediate implication is that output returns faster to potential and generally contracts by less under FA+LD than in the baseline model with no frictions or in the FA-only model, a result that contrasts with the finding in Gertler *et al.* (2003) using simple non-optimized rules. The other key finding is that, once again, although FA and LD imply similar responses of investment, LD tends to make monetary policy more aggressive. Exactly as in the case of the TFP shock, this is optimal in that – under LD – the monetary authority can take advantage of the interest rate/exchange rate UIP channel to affect the exchange rate, and this way bring net worth and investment (and hence output and inflation) faster back to equilibrium.

6 The Fixed Exchange Rate Regime and Optimal Rules

What is left to understand now is what is hence the optimal degree of exchange rate stabilization (given inflation stabilization) in economies with frictions and dollarization. To this end we proceed to search simple optimized rules that maximize a welfare criterion based on households' utility under financial frictions and dollarization. We focus on the three regimes described above, namely 'FIX', 'FLEX' and 'HYB'. For the latter two regimes we compute optimized rules that minimize the expected welfare loss with respect to the feedback parameters $\rho \in [0,1]$, π_θ and π_s. We restrict our search to $\pi_\theta \in [1,5]$: the lower bound ensures the rule satisfies the 'Taylor Principle' and the imposed upper bound avoids large initial jumps in the nominal interest rate.

We search simple rules that are optimal for four model variants (where in model II we set $a = \frac{1}{2}$, i.e. moderate TD, in model IV we set $\varphi = 0.75$, i.e a moderate LD.

Table 3 provides the parameter values that optimize the FLEX and HYB rules in these four cases.[19] Tables 4–7 report variances from simulating each model variant under all shocks for the corresponding simple optimized FIX, FLEX and HYB rule [20] A joint read of these tables points to some interesting results.

- Responding *directly* to the exchange rate, in addition to inflation and output growth is not optimal under liability dollarization or in the presence of financial frictions (FA in particular): the optimal feedback from the exchange rate is zero, or close to zero across all models. Thus, central banks in countries with these features should not attempt to manage the exchange rate nor, more generally, attempt to balance inflation and exchange rate stability objectives. This finding restates the Gilchrist (2003) result obtained using simple non-optimized rules. The reason is clear: financial dollarization weakens the output gap channel and strengthens the exchange rate channel of monetary policy transmission– which gets activated through the UIP via interest rate changes–because, in this case, the cost of capital on which output (and inflation) depend are a function of both the real interest rate and the real exchange rate. Since under financial dollarization exchange rate becomes the key adjustment variable, changes in it are necessary to stabilize inflation by attenuating the financial accelerator effects. Thus fixing the exchange rate or reducing its volatility limits the ability of the central bank to enact stabilizing monetary interventions, and forces it to larger interest rate gyrations instead. These induce larger welfare losses both because the central bank now forgoes the possibility to use the exchange rate to undo financial accelerator effects and because aggressive changes in the interest rate generate adverse balance sheet effects at home by raising strongly the cost of capital, which in turn affects net worth and output.

- Responding *indirectly* to the exchange rate by choosing a consumer price rather than a domestic price inflation target, regime FLEX(C), is also severely sub-optimal. The reasons for this are broadly the same as those for the failure of HYB to improve on FLEX(D).

- With flexible exchange rates, under FA+LD policy tends to be more aggressive, other things equal, with larger gyrations of the interest rate than under no frictions/dollarization. Adding an explicit feedback response to the exchange rate instils yet additional volatility to the interest rate with negative repercussions on all macro

[19] Note there is no 'optimal' FIX regime since the parameter θ_s is simply set at a value sufficiently high to ensure a fixed exchange rate.

[20] We omit to report results on Model V for the reasons described above

variables (Table 7) and a larger welfare loss. In the extreme case of exchange rate fixity ('FIX') results are disastrous;

- The optimal parameters in our simple rules are similar across models, which means that a domestic inflation feedback rule with an added feedback for output is a robust rule with respect to any model uncertainty regarding financial frictions. Emerging market central banks do not have to significantly differentiate they way the set monetary conditions from the way these are set in advanced, relatively frictionless economies;

- Finally, our results indicate that smoothing interest rate changes is desirable independently of the frictions/dollarization features of the economy–and indeed, integral rules always outperform proportional rules.[21]

Two remaining questions remain. Given that there is little or no scope for targeting the nominal exchange rate, what is the welfare cost of maintaining a fixed rate? Second, the Taylor-type rules are only optimal given the constraints implied by the particular inflation and output growth targets, but is sub-optimal compared with the fully optimal commitment rule. What then is the welfare cost of restricting rules in this way? Tables 4–8 provide answers to these questions. These tables provide outcomes in terms of unconditional variances of key variables where the maximized welfare losses Ω_0 are provided and compared with those for the optimal commitment policy. In the final column we provide the percentage consumption equivalent welfare loss compared with the optimal policy derived in Appendix E and given by[22]

$$c_e = \frac{\Omega_0^i - \Omega_0^{OPT}}{(1-\rho)(1-h_C)c_y} \times 10^{-2}, \;\; i = \text{FIX}, \text{FLEX(D)}, \text{FLEX(C)} \tag{66}$$

A number of noteworthy points emerge from these results on welfare costs. First, the fixed exchange rate constraint imposes a cost in terms of a permanent consumption equivalent of $0.48-0.50\%$ for models I and II rising to 1.25% in model IV. The introduction of the FA sees these consumption costs increase significantly and then rise again with the introduction of the LD at the moderate level of $\varphi = 0.75$ (meaning a quarter of the firms borrowing is in dollars). Second, optimized domestic inflation Taylor-type rules mimic the fully optimal rule closely with a very small consumption equivalent loss. The latter rises

[21] As is shown in Batini *et al.* (2004) in an open-economy context, interest rate smoothing is also desirable because it allows the rule to feedback back strongly from the interest rate target, without falling foul of determinacy.

[22] Note that all welfare losses have been normalized by the terms $\frac{1-\beta}{FY}$ - see Appendix E. In addition all variances are in $\%^2$, so that c_e is in $\%$ form.

with the introduction of the FA and again with LD, but remains small. So not only are optimized rules of this simple rule robust, there are only slightly sub-optimal. Third, CPI inflation rules however impose far higher costs from $0.03 - 0.15\%$ as one progresses from model I to model IV.

In one respect the consumption equivalent costs reported up to now are misleading, especially for the FIX regime. The reason for this is to be seen for the unconditional variances reported in these which are very large in the case of FIX and rise for all regimes when we introduce the FA and then LD. Such high variances imply that the interest rate under these optimized or optimal rules will hit the interest rate zero lower bound frequently.[23] The next section addresses this design fault in the rules.

7 Imposing the Nominal Interest Rate Zero Lower Bound

We now modify our interest-rate rules to approximately impose an interest rate ZLB so that this event hardly ever occurs. Although so far only a few emerging market countries have experienced deflationary episodes (Peru and Israel in 2007 are examples of this), most inflation-targeting emerging market countries have chosen low single digit inflation targets (see IMF, 2005), which makes the design of rules robust to ZLB problems germane. As in Woodford (2003), chapter 6, the ZLB constraint is implemented by modifying the single period welfare loss (62) to $L_t + w_r r_{n,t}^2$. Then following Levine *et al.* (2007), the policymaker's optimization problem is to choose w_r and the unconditional distribution for $r_{n,t}$ (characterized by the steady state variance) shifted to the right about a new non-zero steady state inflation rate and a higher nominal interest rate, such that the probability, p, of the interest rate hitting the lower bound is very low. This is implemented by calibrating the weight w_r *for each of our policy rules* so that $z_0(p)\sigma_r < R_n$ where $z_0(p)$ is the critical value of a standard normally distributed variable Z such that prob $(Z \leq z_0) = p$, $R_n = \frac{1}{\beta(1+g_{u_c})} - 1 + \pi^*$ is the steady state nominal interest rate, $\sigma_r^2 = \text{var}(r_n)$ is the unconditional variance and π^* is the new steady state inflation rate. Given σ_r the steady state positive inflation rate that will ensure $r_{n,t} \geq 0$ with probability $1 - p$ is given

[23] As Primiceri (2006) has pointed out, optimal rules with this feature are 'not operational'.

by[24]

$$\pi^* = \max[z_0(p)\sigma_r - \left(\frac{1}{\beta(1+g_{u_c})} - 1\right) \times 100, 0] \tag{67}$$

In our linear-quadratic framework we can write the intertemporal expected welfare loss at time $t = 0$ as the sum of stochastic and deterministic components, $\Omega_0 = \tilde{\Omega}_0 + \bar{\Omega}_0$. Note that $\bar{\Omega}_0$ incorporates in principle the new steady state values of all the variables; however the NK Phillips curve being almost vertical, the main extra term comes from the π^2 term in (E.32). By increasing w_r we can lower σ_r thereby decreasing π^* and reducing the deterministic component, but at the expense of increasing the stochastic component of the welfare loss. By exploiting this trade-off, we then arrive at the optimal policy that, in the vicinity of the steady state, imposes the ZLB constraint, $r_t \geq 0$ with probability $1 - p$.

Tables 8 and 9 show the results of this optimization procedure for the optimal commitment rules and the optimized simple rules respectively for the case of model IV. We choose $p = 0.001$. Given w_r, denote the expected inter-temporal loss (stochastic plus deterministic components) at time $t = 0$ by $\Omega_0(w_r)$. This includes a term penalizing the variance of the interest rate which does not contribute to utility loss as such, but rather represents the interest rate lower bound constraint. Actual utility, found by subtracting the interest rate term, is given by $\Omega_0(0)$. The steady-state inflation rate, π^*, that will ensure the lower bound is reached only with probability $p = 0.001$ is computed using (67). Given π^*, we can then evaluate the deterministic component of the welfare loss, $\bar{\Omega}_0$. Since in the new steady state the real interest rate is unchanged, the steady state involving real variables are also unchanged, so from (62) we can write $\bar{\Omega}_0(0) = w_\pi \pi^{*2}$. Both the ex-ante optimal and the optimal time-consistent deterministic welfare loss that guide the economy from a zero-inflation steady state to $\pi = \pi^*$ differ from $\bar{\Omega}_0(0)$ (but not by much because the steady-state contributions by far outweighs the transitional one).

Table 10 summarizes the outcomes of optimized simple rules and the optimal rule with a ZLB approximately imposed in model IV. Comparing the last columns of tables 10 and 7 we can see that ZLB considerations create a substantial consumption equivalent loss for the fixed exchange rate, c_e, and smaller but significant one for the regimes FLEX(D) and

[24] If the inefficiency of the steady-state output is negligible, then $\pi^* \geq 0$ is a credible new steady state inflation rate. Note that in our LQ framework, the zero interest rate bound is very occasionally hit. Then interest rate is allowed to become negative, possibly using a scheme proposed by Gesell (1934) and Keynes (1936). Our approach to the ZLB constraint (following Woodford, 2003) in effect replaces it with a nominal interest rate variability constraint which ensures the ZLB is hardly ever hit. By contrast the work of a number of authors including Adam and Billi (2007), Coenen and Wieland (2003), Eggertsson and Woodford (2003) and Eggertsson (2006) study optimal monetary policy with commitment in the face of a non-linear constraint $i_t \geq 0$ which allows for frequent episodes of liquidity traps in the form of $i_t = 0$.

FLEX(C), the latter being almost double the former. Under the FE there is no scope for trading off the variance of the nominal exchange rate with other macroeconomic variances that impact on welfare. Thus the *only* way of reducing the probability of hitting the lower bound is to increase the steady state inflation rate which rises to 9% per quarter. This imposes a very large welfare loss reflected in $c_e = 11.4\%$.[25] For the Taylor rules there are some trade-offs between the variance of the nominal interest rate and the variances of inflation, consumption and other variables impacting on welfare. Thus for the optimized rule under a ZLB the variance of the nominal interest rate falls from $2.75\,(\%)^2$ to $2.24\,(\%)^2$ as w_r increases, at a steady state inflation cost of 2.05% per quarter. The consumption equivalent loss of the Taylor rules rises from 0.019% without ZLB concerns to 0.57% for FLEX(D) and 0.83% for FLEX(C), with such concerns.

8 Conclusions

Three clear results emerge from our analysis: first, given our calibration, the financial accelerator has a much larger impact on the performance of the optimized fixed exchange rate, Taylor and hybrid interest rate rules than the presence of transactions dollarization. In particular the costs of a fixed exchange rate regime rises significantly. Second, the introduction of liability dollarization alongside the financial accelerator increases these costs further. Finally, the zero lower bound constraint on the interest rate substantially increases the welfare cost of both the fixed exchange rate constraint, and restricting policy to an optimized Taylor, as opposed to a fully optimal monetary policy rule.

The message for monetary policymakers in emerging market economies struggling with frictions and dollarization is: do not try to achieve a double inflation-exchange rate objectives, since this can backfire and lead to larger losses than commonly believed. You should fear to fix, not fear to float! Furthermore, central banks should not implicitly target the exchange rate by choosing a CPI rather than domestic price inflation target. Finally, the zero lower bound constraint on the interest rate substantially increases the welfare cost of both the fixed exchange rate constraint, and restricting policy to an optimized flex exchange rates Taylor-type rule, as opposed to a fully optimal monetary policy rule. As usual, central banks will have to carefully trade off in setting policy in a a simple and monitorable way with the costs of incurring in welfare losses from the higher risk of hitting the zero bound.

[25] However, full dollarization, for example via a currency board, would result in $r_{n,t} = r^*_{n,t}$ and the ZLB then ceases to be a concern for the domestic country. This would still leave a significant welfare loss for the FIX regime equal to that reported in table 7 of $c_e = 1.25\%$. We are grateful to Marc Giannoni for pointing this out.

All our numerical results of course depend on our choice of calibration. Whilst some experimentation suggests that the qualitative results should be robust with respect to a reasonable choice of alternatives, this will not be necessarily true of our quantitative findings on the welfare costs of various regimes. This suggests that future research could be usefully directed at a systems estimation of the model using Bayesian-Maximum Likelihood methods now popular in the DSGE literature.[26]

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A The Steady State

The BGP steady state for the growth path for the net worth which is given by

$$\bar{N}_{t+1} = \xi_e(1+R)(1+\Theta)\bar{N}_t \tag{A.1}$$

Then if net worth, consumption, output, the wage and capital stock are growing at a rate g per period, a balanced growth path must satisfy

$$\begin{aligned}
1+g &= \xi_e(1+R)(1+\Theta) && \text{(A.2)}\\
\frac{\bar{K}_{t+1}}{\bar{K}_t} &= \frac{\bar{Y}_{t+1}}{\bar{Y}_t} = \frac{\bar{C}_{t+1}}{\bar{C}_t} = \frac{\bar{W}_{t+1}}{\bar{W}_t} = 1+g && \text{(A.3)}\\
\frac{\bar{A}_{t+1}}{\bar{A}_t} &= 1 + \frac{g}{1-\alpha} && \text{(A.4)}
\end{aligned}$$

Since there are no investment adjustment costs at the steady state it follows that

$$\bar{K}_{t+1} = (1-\delta)\bar{K}_t + \bar{I}_t \tag{A.5}$$

It follows from (A.3) that

$$\bar{I}_t = (g+\delta)\bar{K}_t \tag{A.6}$$

and hence the previous assumptions regarding $\Phi(\cdot)$ become $\Phi(g+\delta) = g+\delta$ and $\Phi'(g+\delta) = 1$.

In what follows we denote the (possibly trended) steady state of X_t by X. Then the rest of the steady state is given by

$$\begin{aligned}
C_H &= \mathrm{w}\left(\frac{P_H}{P}\right)^{-\mu} C && \text{(A.7)}\\
C_F &= (1-\mathrm{w})\left(\frac{P_F}{P}\right)^{-\mu} C && \text{(A.8)}\\
P &= \left[\mathrm{w}P_H^{1-\mu} + (1-\mathrm{w})P_F^{1-\mu}\right]^{\frac{1}{1-\mu}} && \text{(A.9)}\\
\frac{W}{P} &= -\frac{1}{\left(1-\frac{1}{\eta}\right)}\frac{U_L}{U_C} && \text{(A.10)}\\
1 &= \beta(1+R_n)(1+g_{u_c}) = \beta(1+R)(1+g_{u_c}) && \text{(A.11)}
\end{aligned}$$

where g_{u_c} is the growth rate of the marginal utility of consumption in the steady state,

$$\begin{aligned}
1+R^k &= (1+\Theta)(1+R) && \text{(A.12)}\\
\Theta &= \Theta\left(\frac{B}{N}\right) = \Theta\left(\frac{QK}{N} - 1\right) && \text{(A.13)}\\
Y &= AK^{\alpha}L^{1-\alpha} - \Phi && \text{(A.14)}\\
\frac{WL}{P_H^W Y} &= 1-\alpha && \text{(A.15)}\\
\frac{Q(R^k+\delta)K}{P_H^W Y} &= \alpha && \text{(A.16)}
\end{aligned}$$

$$
\begin{aligned}
I &= (g+\delta)K && \text{(A.17)}\\
I &= \left[\mathrm{w}_I^{\frac{1}{\rho_I}} I_H^{\frac{\rho_I-1}{\rho_I}} + (1-\mathrm{w}_I)^{\frac{1}{\rho_I}} I_F^{\frac{\rho_I-1}{\rho_I}} \right]^{\frac{\rho_I}{1-\rho_I}} && \text{(A.18)}\\
\frac{I_H}{I_F} &= \frac{\mathrm{w}_I}{1-\mathrm{w}_I}\left(\frac{P_H}{P_F}\right)^{-\rho_I} && \text{(A.19)}\\
P_I &= \left[\mathrm{w}_I P_H^{1-\rho_I} + (1-\mathrm{w}_I) P_F^{1-\rho_I}\right]^{\frac{1}{1-\rho_I}} && \text{(A.20)}\\
Q\Phi'\left(\frac{I}{K}\right) &= \frac{P_I}{P} && \text{(A.21)}\\
P_H &= \hat{P}_H = \frac{P_H^W}{\left(1-\frac{1}{\zeta}\right)} && \text{(A.22)}\\
Y &= C_H + \frac{1}{\nu}[C_H^e + C_H^{e*} + I_H + I_H^*] + \frac{1-\nu}{\nu} C_H^* + G && \text{(A.23)}\\
C_{H,t}^e &= (1-\xi_e)V = (1-\xi_e)(1+R^k)N \equiv s_e C_{H,t} && \text{(A.24)}\\
T &= G && \text{(A.25)}\\
U_{M_H} &= U_C \frac{R_n}{1+R_n} && \text{(A.26)}\\
U_{M_F} &= U_C \frac{R_n^*}{1+R_n^*} && \text{(A.27)}
\end{aligned}
$$

plus the foreign counterparts. The steady steady is completed with

$$
\begin{aligned}
\mathcal{T} &= \frac{P_F}{P_H} && \text{(A.28)}\\
RER &= \frac{SP^*}{P} && \text{(A.29)}\\
U_C &= U_C^* \frac{z_0}{RER} && \text{(A.30)}
\end{aligned}
$$

Units of output are chosen so that $P_H = P_F = 1$. Hence $\mathcal{T} = P = P_I = 1$. Hence with our assumptions regarding $\Phi(\cdot)$ we have that $Q = 1$. We also normalize $S = 1$ in the steady state so that $P_F^* = P_H^* = P^* = P_I^* = 1$ as well. Then the steady state of the risk-sharing condition (A.30) becomes $C = kC^*$ where k is a constant.

B Linearization

Exogenous processes:

$$a_{t+1} = \rho_a a_t + v_{a,t+1} \tag{B.1}$$

$$g_{t+1} = \rho_g g_t + v_{g,t+1} \tag{B.2}$$

$$g^*_{t+1} = \rho^*_g g^*_t + v^*_{g,t+1} \tag{B.3}$$

$$\varepsilon^*_{R,t+1} = \rho^*_R \varepsilon^*_{R,t} + v^*_{R,t+1} \tag{B.4}$$

$$\varepsilon_{P,t+1} = \rho_P \varepsilon_{P,t} + v_{P,t+1} \tag{B.5}$$

$$\varepsilon_{UIP,t+1} = \rho_{UIP} \varepsilon_{UIP,t} + v_{UIP,t+1} \tag{B.6}$$

Predetermined variables

$$k_{t+1} = \frac{1-\delta}{1+g} k_t + \frac{\delta+g}{1+g} i_t \tag{B.7}$$

$$k^*_{t+1} = \frac{1-\delta^*}{1+g} k^*_t + \frac{\delta^*+g}{1+g} i^*_t \tag{B.8}$$

$$\begin{aligned} n_t &= \frac{\xi_e}{1+g}\Big[\frac{1}{n_k} r^k_{t-1} + (1+\Theta)(1+R) n_{t-1} \\ &+ \left(1 - \frac{1}{n_k}\right)\left[(1+R)\theta_{t-1} + (1+\Theta)(\varphi r_{t-1} + (1-\varphi)(r^*_{t-1} + (1+R)(rer_t - rer_{t-1})\right]\Big] \end{aligned} \tag{B.9}$$

$$n^*_t = \frac{\xi^*_e}{1+g}\Big[\frac{1}{n^*_k} r^{k*}_t + (1+\Theta^*)(1+R) n^*_{t-1} + \left(1 - \frac{1}{n^*_k}\right)\left[(1+R)\theta^*_{t-1} + (1+\Theta^*) r^*_{t-1}\right]\Big] \tag{B.10}$$

where $r_{t-1} = r_{n,t-1} - \pi_t$ and $r^*_{t-1} = r^*_{n,t-1} - \pi^*_t$ are the ex post real interest rates.

$$s_t = s_{t-1} + rer_t - rer_{t-1} + \pi_t - \pi^*_t \tag{B.11}$$

Non-predetermined variables:

$$\begin{aligned} (1-\delta) E_t(q_{t+1}) &= (1+R^k) q_t - (R^k + \delta) x_t \\ &+ E_t(r^k_t) \end{aligned} \tag{B.12}$$

$$\begin{aligned} (1-\delta^*) E_t(q^*_{t+1}) &= (1+R^*) q^*_t - (R^{k*} + \delta^*) x^*_t \\ &+ E_t(r^{k*}_{t+1}) \end{aligned} \tag{B.13}$$

$$E_t u_{c,t+1} = u_{c,t} - \frac{r_{n,t}}{1+R} + E_t \pi_{t+1} \tag{B.14}$$

$$E_t u^*_{c,t+1} = u^*_{c,t} - \frac{r^*_{n,t}}{1+R} + E_t \pi^*_{F,t+1} \tag{B.15}$$

$$\beta E_t \pi_{H,t+1} = \pi_{H,t} - \lambda_H mc_t \tag{B.16}$$

$$\beta E_t \pi^*_{F,t+1} = \pi^*_{F,t} - \lambda^*_F mc^*_t \tag{B.17}$$

$$\left(1+\frac{1+g}{1+R}\right)i_t = \frac{1+g}{1+R}E_t i_{t+1} + i_{t-1} + \frac{1}{(1+g)^2 S''(1+g)}(q_t - p_{I,t} + p_t) \quad \text{(B.18)}$$

$$\left(1+\frac{1+g}{1+R}\right)i^*_t = \frac{1+g}{1+R}E_t i^*_{t+1} + i^*_{t-1} + \frac{1}{(1+g)^2 S''(1+g)}(q^*_t + p^*_{I,t} - p^*_t) \quad \text{(B.19)}$$

Instrument

$$r_{n,t} = \text{exogenous instrument} \quad \text{(B.20)}$$

Outputs:

$$mc_t = u_{l,t} - u_{c,t} + l_t - y_t + p_t - p_{H,t} \quad \text{(B.21)}$$

$$mc^*_t = u^*_{l,t} - u^*_{c,t} + l^*_t - y^*_t + p^*_t - p^*_{F,t} \quad \text{(B.22)}$$

$$\begin{aligned} u_{c,t} &= \frac{(1-\varrho)(1-\sigma)-1}{1-h_C}(c_t - h_C c_{t-1}) - \frac{\varrho(1-\sigma)}{1-L}(l_t - L\varepsilon_{L,t}) + \varepsilon_{C,t} \\ &+ \varpi[\bar{a} r_{n,t} + (1-\bar{a}) r^*_{n,t}] \end{aligned} \quad \text{(B.23)}$$

$$\begin{aligned} u^*_{c,t} &= \frac{(1-\varrho^*)(1-\sigma^*)-1}{1-h^*_C}(c^*_t - h^*_C c^*_{t-1}) - \frac{\varrho^*(1-\sigma^*)}{1-L^*}(l^*_t - L^*\varepsilon^*_{L,t}) + \varepsilon^*_{C,t} \\ &+ \varpi(1) r^*_{n,t} \end{aligned} \quad \text{(B.24)}$$

$$\begin{aligned} u_{l,t} &= \frac{1}{1-h_C}(c_t - h_C c_{t-1}) + \frac{1}{1-L}(l_t - \varepsilon_{L,t}) + u_{c,t} + \varepsilon_{C,t} \\ &+ \varpi_L[\bar{a} r_{n,t} + (1-\bar{a}) r^*_{n,t}] \end{aligned} \quad \text{(B.25)}$$

$$u^*_{l,t} = \frac{1}{1-h^*_C}(c^*_t - h^*_C c^*_{t-1}) + \frac{1}{1-L^*}(l^*_t - \varepsilon^*_{L,t}) + u^*_{c,t} + \varepsilon^*_{C,t} + \varpi^*_L r^*_{n,t} \quad \text{(B.26)}$$

$$\begin{aligned} y_t &= \alpha_{C,H} c_t + \alpha^e_{C,H} c^e_t + \alpha^*_{C,H} c^*_t + \alpha_{I,H} i_t + \alpha^*_{I,H} i^*_t + \alpha_G g_t \\ &+ [\mu(\alpha_{C,H} + \alpha^e_{C,H})(1-\mathrm{w}) + \mu^* \alpha^*_{C,H} \mathrm{w}^* + \rho_I \alpha_{I,H}(1-\mathrm{w}_I) + \rho^*_I \alpha^*_{I,H} \mathrm{w}^*_I]\tau_t \end{aligned} \quad \text{(B.27)}$$

$$\begin{aligned} y^*_t &= \alpha^*_{C,F} c^*_t + \alpha^{*e}_{C,F} c^{*e}_t + \alpha_{C,F} c_t + \alpha^e_{C,F} c^e_t + \alpha^*_{I,F} i^*_t + \alpha_{I,F} i_t + \alpha^*_G g^*_t \\ &- [\mu^*(\alpha^*_{C,F} + +\alpha^{*e}_{C,F}) c^{*e}_t (1-\mathrm{w}^*) + \mu \alpha_{C,F} \mathrm{w} + \rho^*_I \alpha^*_{I,F}(1-\mathrm{w}^*_I) + \rho_I \alpha_{I,F} \mathrm{w}_I]\tau_t \\ &= c^*_y c^*_t + i^*_y i^*_t + g^*_y g^*_t \end{aligned} \quad \text{(B.28)}$$

(Note small open economy results: $\mathrm{w} = \omega$, $\mathrm{w}_I = \omega_I$, $\mathrm{w}^* = \mathrm{w}^*_I = 1$)

$$c^e_t = n_t \quad \text{(B.29)}$$

$$c^{e*}_t = n^*_t \quad \text{(B.30)}$$

$$rer^r_t = u^*_{c,t} - u_{c,t} \quad \text{(B.31)}$$

$$\hat{rer}_t = u^*_{c,t} - \hat{u}_{c,t} \quad \text{(B.32)}$$

$$\omega \tau_t = rer_t \quad \text{(B.33)}$$

$$\theta_t = \chi_\theta(n_t - k_t - q_t) + \epsilon_{P,t} \tag{B.34}$$

$$\theta_t^* = \chi_\theta^*(n_t^* - k_t^* - q_t^*) + \epsilon_{P,t}^* \tag{B.35}$$

$$E_t(r_t^k) = (1+R)\theta_t + (1+\Theta)E_t(r_t) \tag{B.36}$$

$$E_t(r_t^{k*}) = (1+R)\theta_t^* + (1+\Theta^*)E_t(r_t^*) \tag{B.37}$$

$$r_{t-1}^k = (1-\delta)q_t - (1+R^k)q_{t-1} + (R^k+\delta)x_{t-1} \tag{B.38}$$

$$r_{t+1}^{k*} = (1-\delta^*)q_t^* - (1+R^{k*})q_{t-1}^* + (R^{k*}+\delta^*)x_{t-1}^* \tag{B.39}$$

$$E_t(r_t) = r_{n,t} - E_t(\pi_{t+1}) \tag{B.40}$$

$$E_t(r_t^*) = r_{n,t}^* - E_t(\pi_{t+1}^*) \tag{B.41}$$

$$p_t - p_{H,t} = (1-\mathrm{w})\tau_t \to (1-\omega)\tau_t \text{ as } n \to 0 \tag{B.42}$$

$$(\text{ Note } p_t^* - p_{F,t}^* = (1-\mathrm{w}^*)\tau^* \to 0)$$

$$p_{I,t} - p_t = (\mathrm{w} - \mathrm{w}_I)\tau_t \to (\omega - \omega_I)\tau_t \tag{B.43}$$

$$(\text{ Note } p_{I,t}^* - p_t^* = (1-\mathrm{w}_I^*)\tau_t \to 0)$$

$$\pi_t = \pi_{H,t} + (1-\omega)\Delta\tau_t \tag{B.44}$$

$$\pi_t^* = \pi_{F,t}^* \tag{B.45}$$

$$\pi_{F,t} = \pi_{H,t} + \Delta\tau_t \tag{B.46}$$

$$\pi_{H,t}^* = \pi_{F,t}^* - \Delta\tau_t \tag{B.47}$$

$$rf_t = \chi_R(r_{n,t} - r_{n,t}^*) \tag{B.48}$$

$$(1-\alpha)l_t = \frac{1}{\phi_F}y_t - a_t - \alpha k_t \tag{B.49}$$

$$(1-\alpha)l_t^* = \frac{1}{\phi_F^*}y_t^* - a_t^* - \alpha k_t^* \tag{B.50}$$

$$x_t = y_t + mc_t + p_{H,t} - p_t - k_t \tag{B.51}$$

$$x_t^* = y_t^* + mc_t^* - k_t^* \tag{B.52}$$

$$E_t\pi_{t+1} = \mathrm{w}E_t\pi_{H,t+1} + (1-\mathrm{w})E_t\pi_{F,t+1} \tag{B.53}$$

$$E_t\pi_{F,t+1} = E_t rer_{t+1} - rer_t + E_t\pi_{t+1} - E_t\pi_{t+1}^* + E_t\pi_{F,t+1}^* \tag{B.54}$$

$$E_t rer_{t+1} = E_t u_{c,t+1}^* - E_t u_{c,t+1} \tag{B.55}$$

$$r_{n,t}^* = \rho_i^* r_{n,t-1}^* + (1-\rho_i^*)\theta_\pi^*\pi_{F,t}^* + \varepsilon_{R,t}^* \tag{B.56}$$

$$q_t^k = q_t - p_{I,t} + p_t \tag{B.57}$$

$$\text{Note } q_t^{k*} = q_t^*$$

Foreign Asset Accumulation and Modified UIP

Linearizing around $B_F = TB = 0$ we define

$$b_{F,t} \equiv \frac{S_t(B_{F,t} + M_{F,t})}{P_{H,t}Y_t} \tag{B.58}$$

$$tb_t \equiv \frac{TB_t}{P_{H,t}Y_t} \tag{B.59}$$

Then we have in linearized form

$$\begin{aligned} \beta b_{F,t} &= \frac{1}{1+g} b_{F,t-1} + tb_t \\ tb_t &= y_t - \alpha_{C,H} c_t - \alpha^e_{C,H} c^e_t - i_y i_t - g_y g_t - (c_y + i_y)(p_t - p_{H,t}) - i_y(p_{I,t} - p_t) \end{aligned} \tag{B.60}$$

The real exchange rate is the risk-sharing value plus a risk premium deviation given by the system

$$rer_t = rer^r_t + rer^d_t \tag{B.61}$$

$$rer^r_t = u^*_{c,t} - u_{c,t} \tag{B.62}$$

$$E_t[rer^d_{t+1}] = rer^d_t + \delta_r b_{F,t} + \varepsilon_{UIP,t} \tag{B.63}$$

C Calibration and Estimation

We begin with estimates of the processes describing the exogenous shocks.

Shock parameters

We require the AR1 persistence parameters ρ_a, ρ_g, ρ^*_g, ρ^*_r, ρ_P, ρ_{UIP} and the corresponding standard deviations of white noise processes, sd_a, sd_g etc. The following have been estimate by OLS

Peru's TFP shock (A_t): AR coefficient: 0.59, SE=1.1%

Peru's Fiscal Shock ($\frac{G_t}{Y_t}$): AR coefficient: 0.97, SE=0.2%

US fiscal shock ($\frac{G_t}{Y_t}$): AR coefficient: 0.78, SE=0.8%

US Taylor Rule:

$$r^*_{n,t} = 0.94 r^*_{n,t-1} + 0.069 \pi^*_{F,t} + 0.22(y^*_t - y^*_{t-1}) + \epsilon^*_{R,t} \tag{C.1}$$

$SE(\epsilon_R) = 0.36\%$. Note that the long run of this rule satisfies the Taylor principle that the real interest rate should respond positively to an increase in inflation.

UIP shock: Castillo *et al.* (2006) provide the following estimate of the shock in (B.63): AR coefficient=0.96, SE=0.32%

External finance premium shock: In the absence of any estimates in the literature this shock is calibrated to take central values for financial shocks: AR coefficient=0.95, SE=0.5%

Preferences

Risk Aversion Parameters: Estimates in the literature suggests range $\sigma \in [2, 5]$. However, for the US Bayesian estimates suggest a range $\sigma^* \in [2, 3]$. Our central estimates are $\sigma = 3$, $\sigma^* = 2$.

Discount Factors: A standard choice is $\beta = \beta^* = 0.99$

Working Day: A standard value is $L^* = 0.40$ for the US. We choose a slightly higher value $L = 0.5$ for Peru.

Habit Parameters: $h_C = 0.7$ (CMT), $h_C^* = 0.5$ (LOWW)

Substitution Elasticity: A standard choice for small open economies is $\mu = \mu^* = 1.5$.

Elasticity of the marginal utility of consumption with respect to money balances Ψ, Ψ^*: We examine a range $\Psi, \Psi^* \in [0.01, 0.03]$ for which money balances and consumption are complements.

Home currency consumption transactions: $a \in [0, 1]$, $\chi_M = 4$. estimated by CMT.

Technology

Depreciation Rates: A standard choice is $\delta = \delta^* = 0.025$

Common World Growth Rate: We choose a realistic common world growth rates: $g = g^* = 3\%$ per annum

Investment Adjustment Costs: We match Peru with European data using an estimate from SW, for US we use LOWW obtaining $S''(1+g) = 6.0$, $(S''(1+g))^* = 4.0$ from SW

Capital Shares: $\alpha = 0.5$ (CMT), $\alpha^* = 0.33(LOWW)$

Investment Substitution Elasticities: $\rho_I = \rho_I^* = 0.25$ (GGN)

Fixed Costs: $\frac{F}{Y} = 0.4$ (SW).

Financial Accelerator

Elasticity: $\chi_\theta = -0.065$, $\chi_\theta^* = -0.05$ (BGG)

Home currency borrowing for capital: $\varphi \in [0, 1]$

Survival rate: $\xi_e = \xi_e^* = 0.93$ (GGN)
Asset/Debt Ratio: $n_k = 0.4$, $n_k^* = 0.7$ (BGG)
Risk Premium: $\Theta = 0.035$, $\Theta^* = 0.05$ (BGG)

Market Power

Labour Market Power: $\eta = 3$ (SW), corresponding to a 50% mark-up, $\eta^* = 6$, corresponding to a 20% mark-up.
Product Market Power: $\zeta = 7.67$ corresponding to a 15% (SW, LOWW).

Pricing

Calvo Contract: a standard value $\xi_H = \xi_F^* = 0.66$, corresponding to 3 quarter price contracts on average (see CMT)

Consumption, Investment, Money Balance and Trade Shares:

Standard values for the US are $c_y^* = 0.6$, $i_y^* = 0.2$, $g_y = 0.2$ and $z_y = 0.25$ (the latter $z_y = \frac{Z}{PY}$ is money stock as a proportion of quarterly GDP). For Peru we choose $c_y = 0.7$, $i_y = 0.15$, $g_y = 0.1.5$ and $z_y = 0.25$ (as for the US).
Trade Shares: Total exports and imports are around 25% for Peru so $0.25 = cs_{imports} + is_{imports} = cs_{exports} + is_{exports}$ for balanced trade. Data on consumption and capital goods exports show $\frac{is_{imports}}{cs_{imports}} = 1.6$ and $\frac{is_{exports}}{cs_{exports}} = 0.1$. Hence we choose $cs_{imports} = 0.10$, $is_{imports} = 15$, $cs_{exports} = 0.23$ and $i_{imports} = 0.02$.

Derived Parameters:

Given these estimates and data observations we can now calibrate the following parameters:

Preference Parameters, b, θ, ϱ, are found by solving the set of equations

$$\begin{aligned}
\frac{W(1-L)}{PC} &= \frac{(1-\alpha)(1-L)}{c_y L} \\
\Psi &= \frac{(1-b)[(1-\varrho)(1-\sigma)-1+\frac{1}{\theta}}{bcz^{\frac{\theta-1}{\theta}}+1-b} \\
\frac{\Phi}{C\Phi_C} &= \frac{(1-b)cz^{\frac{1-\theta}{\theta}}+b}{b} \\
cz &\equiv \frac{C(1-h_C)}{Z}
\end{aligned}$$

$$
\begin{aligned}
\varrho &= \frac{(1-\frac{1}{\eta})W(1-L)/PC}{\frac{\Phi}{C(1-h_C)\Phi_C}+(1-\frac{1}{\eta})W(1-L)/PC} \\
\frac{b(1-h_C)}{1-b}cz^{-\frac{1}{\theta}} &= \frac{1+R}{R}
\end{aligned}
$$

For central values of σ, assuming $\Psi = 0.01$, we obtain: $b = 0.95$, $\theta = 0.28$, $\varrho = 0.17$ for Peru data and $b^* = 0.99$, $\theta = 0.39$ and $\varrho = 0.66$ for US data.

Demand elasticities calibrated from trade data:

$$
\begin{aligned}
\alpha_{C,H} &= (c_y - cs_{imports})(1-s_e) \\
\alpha^e_{C,H} &= (c_y - cs_{imports})s_e \\
\alpha^*_{C,H} &= cs_{exports} \\
\alpha_{I,H} &= i_y - is_{imports} \\
\alpha^*_{I,H} &= is_{exports} \\
\alpha^*_{C,F} &= c^*_y \\
\alpha^{e*}_{C,F} &= 0 \\
\alpha_{C,F} &= 0 \\
\alpha^*_{I,F} &= i^*_y \\
\alpha_{I,F} &= 0 \\
\alpha_G &= g_y \\
\alpha^*_G &= g^*_y
\end{aligned}
$$

Note the small open economy implication that $\alpha_{C,F} = \alpha_{I,F} = 0$. Then we have

$$
\begin{aligned}
\omega &= \frac{\alpha_{C,H} + \alpha^e_{C,H}}{c_y} = \frac{c_y - cs_{imports}}{c_y} \\
\omega_I &= \frac{\alpha_{I,H}}{i_y}
\end{aligned}
$$

Remaining calibrated parameters are:

$$
\begin{aligned}
g_{u_c} &= (1+g)^{(1-\varrho)(1-\sigma)-1} - 1 \\
R &= \frac{1}{\beta(1+g_{u_c})} - 1 \\
R^k &= (1+\Theta)(1+R) - 1 \\
\bar{a} &= \bar{a}(a) = a^{\chi_M}/(a^{\chi_M} + (1-a)^{\chi_M})
\end{aligned}
$$

$$
\begin{aligned}
\alpha &= \left(a + a^{1-\chi}(1-a)^{\chi}\right)^{\frac{\theta}{\chi-1}} \left(\frac{(1-b)a}{b(1-\beta)}\right)^{\theta} \\
&= \left(\frac{(1-b)}{b(1-\beta)}\right)^{\theta} \text{ for } a = 1 \text{ and } a \to 0 \\
&= \frac{1}{2^{\theta}} \left(\frac{(1-b)}{b(1-\beta)}\right)^{\theta} \text{ for } a = \frac{1}{2} \\
\alpha^* &= \left(\frac{(1-b^*)}{b^*(1-\beta)}\right)^{\theta^*} \text{ (Note : } a^* = 1) \\
b_1 &= b_1(a) = \frac{b}{\left(b + (1-b)\alpha^{\frac{\theta-1}{\theta}}\right)} \\
\varpi &= \varpi(a) = \frac{\beta}{1-\beta}[(1-(1-\varrho)(1-\sigma))\theta - 1](1-b_1) \\
\lambda_H &= \frac{(1-\beta\xi_H)(1-\xi_H)}{\xi_H} \\
\chi_R &= \frac{\chi_M}{R_n(1+R_n)} \\
k_y &= \frac{i_y}{g+\delta} \\
s_e &= \frac{(1-\xi_e)n_k k_y}{\xi_e c_y} \\
\varpi_L &= \varpi_L(a) = \frac{\beta}{1-\beta}(1-\theta)(1-b_1)
\end{aligned}
$$

D Proof of Propositions 1, 2 and Corollary 2

Proposition 1: To study the 'FIX' regime, we need to augment the system with a definitional equation relating the change in the nominal exchange rate to the change in the terms of trade and inflation. Firstly, we assume that foreign prices are fixed, so in log terms $0 = \Delta p^*_{F,t} = \Delta(p_{F,t} - s_t) = \Delta(p_{H,t} + \tau_t - s_t)$, where τ_t is the terms of trade in deviation form. Thus

$$s_t = s_{t-1} + \tau_t - \tau_{t-1} + \pi_{Ht} \tag{D.1}$$

In addition, from the first-order conditions for consumption, we have a relationship between the real exchange rate and marginal utility of consumption $rer_t = u^*_{c,t} - u_{c,t}$, and linearization of (12) yields $rer_t = \omega\tau_t$. Hence

$$s_t = s_{t-1} - \frac{1}{\omega}(u_{ct} - u_{c,t-1} - (u^*_{c,t} - u^*_{c,t-1})) + \pi_{Ht} \tag{D.2}$$

Note that the implication of this equation is that feedback on the nominal exchange rate via (56) is a form of 'integral control' (i.e. a sum of all past values) on inflation. It is known that integral control rules are very robust in terms of their stabilization properties.

Now put $r_{n,t} = r^*_{n,t} + \theta_s s_t$ as discussed above; it is now easy to show that taken together with (57), this implies

$$E_t s_{t+1} = (1 + \theta_s) s_t \tag{D.3}$$

from which we deduce that the nominal exchange rate is given by $s_t = 0$ for all t. Note that this implies from (D.2) that $u_{c,t}$ and $\pi_{H,t}$ are related under this feedback regime and therefore cannot 'jump' independently of one another. Thus we require that the part of the system which describes the joint behaviour of these two variables must have one stable and one unstable eigenvalue. It is easy now to ascertain that their joint characteristic equation becomes

$$(z-1)(\beta z - 1) - \gamma\omega z = 0 \tag{D.4}$$

where z is the forward operator. It is also easy to show that one root of this equation is greater than 1, and the other lies between 0 and 1. Hence proposition 1 follows

Proposition 2: Ignoring all exogenous and stochastic variables, yields a characteristic equation for (54), (57) and (60) given by

$$(z-\rho)[(z-1)(\beta z - 1) - \gamma\omega z] + (1-\rho)\theta_\pi z[\kappa(z-1) + \omega\gamma] = 0 \tag{D.5}$$

The effects of dollarization can be assessed through the variation in κ, which is a function of a, where $1 - a$ is the degree of dollarization.

As pointed out in the previous section, the case of no dollarization is easily seen to be equivalent to that of a separable utility function. Indeed, for the case $\omega = 1$, this is equivalent to the case of a closed economy. For the case of a partially dollarized economy, $\kappa > 0$ is possible when consumption and real balances are complements, and it turns out that the results depend on the degree of dollarization.

For determinacy, since there are two jump variables, we require exactly two unstable roots. First note that when $\theta_\pi = 0$, the eigenvalues of the system are given by ρ and the roots of $(z-1)(\beta z - 1) - \gamma\omega z$; it is easy to show that one of the latter roots is greater and the other is less than 1, so the system is indeterminate. As $\theta_\pi \to \infty$, the roots tend to $-\infty$ and $1 - \omega\gamma/\kappa$, so that the system has two unstable roots if $1 - \omega\gamma/\kappa < -1$, as in (b), as required for determinacy, but only one unstable root for (b).

Batini *et al.* (2004) describe the root locus method that enables one to track the path of the roots in the complex plane as θ_π changes. In this case, it is easy to show that the smaller of the two stable roots heads for $z = 0$ as θ_π increases to ∞. Also, as θ_π increases to a value slightly beyond 1, the other two roots move closer to one another. They merge into a double root at a value of $z > 1$; to show this, we note that $z = 1$ when $\theta_\pi = 1$, so

we need to prove that increasing θ_π beyond 1 leads to a root larger than 1. It is trivial to show that this follows from the fact that

$$\left.\frac{\partial z}{\partial \theta_\pi}\right|_{\theta_\pi=z=1} = \frac{\gamma\omega}{\gamma\omega + (1-\rho)(1-\beta-\kappa)} \tag{D.6}$$

This is greater than 0 for both (a) and (b). From this double root there are then two branches out into the complex plane, which merge for a much larger value of θ_π on to the negative part of the real axis, and then the roots diverge, one to $-\infty$, and the other to $1-\omega\gamma/\kappa$. Thus for case (b), there are two unstable roots for all θ_π provided that the root locus does not pass through the unit circle. Likewise for (a), if it does not pass through the unit circle, then there are two unstable roots for $1 < \theta_\pi < \bar{\theta}_\pi$, where $\bar{\theta}_\pi$ is the value of θ_π such that there is a root at $z = -1$; there is an additional proviso, that the root locus passes through the point -1 from the left. But this follows from

$$\left.\frac{\partial z}{\partial \theta_\pi}\right|_{z=-1} = \frac{(1-\rho)(2\kappa-\gamma\omega)}{(1+\rho)(1-\beta) + (2(1+\beta)+\gamma\omega)\frac{\gamma\omega-(1-\rho)\kappa}{2\kappa-\gamma\omega}} \tag{D.7}$$

which is also greater than 0 for case (b). Finally we need to show that when the root locus is off the real line, it does not cross the unit circle, which is characterized by $z = e^{i\psi} = \cos\psi + i\sin\psi$. To find a potential crossing, we substitute this into (D.5) (with $\rho = 0$, $j = 0$), then multiply by $e^{i\psi}$ and equate real and imaginary parts to 0. These yield

$$\begin{aligned} 0 &= \beta\cos 2\psi - (1+\beta+\omega\gamma+\rho+\rho\beta)\cos\psi + 1 + \rho(1+\beta+\omega\gamma) \\ &\quad +\theta_\pi(1-\rho)(\kappa\cos\psi + \omega\gamma - \kappa) \qquad \text{(D.8)} \\ 0 &= \beta\sin 2\psi - (1+\beta+\omega\gamma-\rho+\rho\beta)\sin\psi + \theta_\pi(1-\rho)\kappa\sin\psi \qquad \text{(D.9)} \end{aligned}$$

There are obviously roots at $\sin\psi = 0$, which corresponds to (i) $z = 1$, $\theta_\pi = 1$, which explains why we there is indeterminacy for $\theta_\pi < 1$ (ii) $z = -1$, which only corresponds to positive θ_π for case (a). The alternative, after removing the factor $\sin\psi$ from (D.9) is that $0 = 2\beta\cos\psi - (1+\beta+\omega\gamma-\rho+\rho\beta) + \theta_\pi(1-\rho)\kappa$. Substituting for $\cos\psi$ from this expression into (D.8) yields a unique value of θ_π. But for the locus to branch at a value of $z > 1$, and return to the real line at a value of $z < -1$, it needs to cross the unit circle twice, but this is ruled out by this unique value of θ_π.[27]

Corollary 2: First note that of all the parameters in (D.5), only κ is dependent on

[27] For the case $(1-\rho)\kappa > \gamma\omega$, the unit circle could be crossed once by the root locus, implying that there may be a limited range of determinacy.

dollarization, via the term $\bar{a}(1-b_1)$. The effect of increasing a on this term is given by

$$\frac{d(\bar{a}(1-b_1))}{da} = \frac{\chi_M B(a^{\chi_M}+(1-a)^{\chi_M})^{\frac{\theta-1}{\chi_M-1}}}{(a^{\chi_M}+(1-a)^{\chi_M})^2(b+B(a^{\chi_M}+(1-a)^{\chi_M})^{\frac{\theta-1}{\chi_M-1}})^2}\Bigg[$$
$$a^{\chi_M-1}(1-a)^{\chi_M-1}(b+B(a^{\chi_M}+(1-a)^{\chi_M})^{\frac{\theta-1}{\chi_M-1}}) + \frac{\theta-1}{\chi_M-1}ba^{\chi_M}(a^{\chi_M-1}-(1-a)^{\chi_M-1})\Bigg] \tag{D.10}$$

where $B=(1-b)^{\theta}b^{1-\theta}(1-\beta)^{1-\theta}$.

Given that $\theta<1$, and in our calibrations we use $\chi_M>1$, it is easy to see that this is increasing for $a<\frac{1}{2}$. But dollarization is associated with decreasing a, which leads to a decrease in κ as a decreases from $\frac{1}{2}$ to 0. Thus we have Corollary 2 in the main text.

E Quadratic Approximation of the Welfare Loss

The basic idea is to obtain the quadratic approximation to the social planner's problem, coupled with a term in inflation, which arises from price dispersion. We adopt a 'small distortions' approximation which is accurate as long as the zero-inflation steady state is close to the social optimum. As we have noted in the main text, the existence of external habit offsets the distortions in the product and labour markets. For our calibrated high value for the habit parameter h_C, this leaves the steady state of the decentralized economy close to the social optimum, justifying the small distortions approximation.

Consider the social planner's problem to maximize

$$\sum_{t=0}^{\infty}\beta^t\frac{(C_t-h_CC_{t-1})^{(1-\varrho)(1-\sigma)}(1-L_t)^{\varrho(1-\sigma)}}{1-\sigma} \tag{E.1}$$

subject to the (resource) constraints:

$$1-\omega+\omega T_t^{\mu-1}=E_t^{\mu-1} \qquad 1-\omega_I+\omega_I T_t^{\rho_I-1}=E_{It}^{\rho_I-1} \qquad K_t=(1-\delta)K_{t-1}+I_t \tag{E.2}$$

$$Y_t+\Phi=A_tK_{t-1}^{\alpha}L_t^{1-\alpha}=\omega E_t^{-\mu}T_t^{\mu}C_t+(1-\omega^*)T_t^{\mu}C_t^*+\omega_I E_{It}^{-\rho_I}T_t^{\rho_I}I_t+(1-\omega_I^*)T_t^{\rho_I^*}I_t^*+G_t \tag{E.3}$$

where the terms of trade are given by $T=P_F/P_H$, and the real exchange rate as $E=SP^*/P$, so that $E^{1-\mu}=P_F^{1-\mu}/(\omega P_H^{1-\mu}+(1-\omega)P_F^{1-\mu})$. There is a risk-sharing condition given by

$$E_t=U_{C_t^*}^*/U_{C_t} \qquad E_tC_t^{(1-\varrho)(1-\sigma)-1}(1-L_t)^{\varrho(1-\sigma)}=C_t^{*(1-\varrho)(1-\sigma)-1}(1-L_t^*)^{\varrho(1-\sigma)} \tag{E.4}$$

where we assume initial wealth per capita is the same in each country.

The Lagrangian for the problem may be written as

$$\sum_{t=0}^{\infty}\beta^t\Bigg[\frac{(C_t-Z_t)^{(1-\varrho)(1-\sigma)}(1-L_t)^{\varrho(1-\sigma)}}{1-\sigma}+\lambda_{1t}(Z_t-h_C C_{t-1})$$
$$+\lambda_{2t}(\omega E_t^{-\mu}T_t^{\mu}C_t+(1-\omega^*)T_t^{\mu}C_t^*+\omega_I E_{It}^{-\rho_I}T_t^{\rho_I}I_t+(1-\omega_I^*)T_t^{\rho_I^*}I_t^*+G_t-A_tK_{t-1}^{\alpha}L_t^{1-\alpha})$$
$$+\lambda_{3t}(1-\omega+\omega T_t^{\mu-1}-E_t^{\mu-1})+\lambda_{4t}(1-\omega_I+\omega_I T_t^{\rho_I-1}-E_{It}^{\rho_I-1})$$
$$+\lambda_{5t}(E_tC_t^{(1-\varrho)(1-\sigma)-1}(1-L_t)^{\varrho(1-\sigma)}-U_{C^*})+\lambda_{6t}(K_t-(1-\delta)K_{t-1}-I_t)\Bigg] \tag{E.5}$$

First-order conditions with respect to C, Z, E, T, E_I, I, L, K yield

$$\begin{aligned}
0 &= (1-\varrho)(C-Z)^{(1-\varrho)(1-\sigma)-1}(1-L)^{\varrho(1-\sigma)}-\beta\lambda_1 h_C+\lambda_2\omega E^{-\mu}T^{\mu} \\
&\quad +\lambda_5[(1-\sigma)(1-\varrho)-1]E(C-Z)^{(1-\varrho)(1-\sigma)-1}(1-L)^{\varrho(1-\sigma)} && \text{(E.6)}\\
0 &= -(1-\varrho)(C-Z)^{(1-\varrho)(1-\sigma)-1}(1-L)^{\varrho(1-\sigma)}+\lambda_1 \\
&\quad +\lambda_5[(1-\sigma)(1-\varrho)-1]E(C-Z)^{(1-\varrho)(1-\sigma)-1}(1-L)^{\varrho(1-\sigma)} && \text{(E.7)}\\
0 &= -\lambda_2\mu\omega E^{-\mu-1}T^{\mu}C-\lambda_3(\mu-1)E^{\mu-2}+\lambda_5(C-Z)^{(1-\varrho)(1-\sigma)-1}(1-L)^{\varrho(1-\sigma)} && \text{(E.8)}\\
0 &= \lambda_2 T^{\mu-1}(\omega E^{-\mu}C+(1-\omega)C^*)+\lambda_2\rho_I T^{\rho_I-1}(\omega_I E_I^{-\rho_I}I+(1-\omega_I)I^* \\
&\quad +\lambda_3\omega(\mu-1)T^{\mu-2}+\lambda_4\omega_I(\rho_I-1)T^{\rho_I-2} && \text{(E.9)}\\
0 &= -\lambda_2\rho_I\omega_I E_I^{-\rho_I-1}T^{\rho_I}I-\lambda_4(\rho_I-1)E_I^{\rho_I} && \text{(E.10)}\\
0 &= \lambda_2\omega_I E_I^{-\rho_I}T_{\rho_I}-\lambda_6 && \text{(E.11)}\\
0 &= -\varrho(C-Z)^{(1-\varrho)(1-\sigma)}(1-L)^{\varrho(1-\sigma)-1}-\lambda_2 A(1-\alpha)K^{\alpha}L^{-\alpha} \\
&\quad -\lambda_5\varrho(1-\sigma)E(C-Z)^{(1-\varrho)(1-\sigma)-1}(1-L)^{\varrho(1-\sigma)-1} && \text{(E.12)}\\
0 &= \lambda_2\alpha A K^{\alpha-1}L^{1-\alpha}+\lambda_6(\frac{1}{\beta}-1+\delta) && \text{(E.13)}
\end{aligned}$$

In steady-state these satisfy

$$\alpha A\left(\frac{L}{K}\right)^{1-\alpha}=\omega_I(\frac{1}{\beta}-1+\delta)=\omega_I R_K \qquad \lambda_4(1-\rho_I)=\lambda_2\rho_I\omega_I I \tag{E.14}$$

$$\lambda_3\omega(1-\mu)=\lambda_2(\mu_C+\rho_I(1-\omega_I^2)I) \qquad (1-\beta h_C)\lambda_1=-\omega\lambda_2 \tag{E.15}$$

$$\lambda_5 F=-\frac{\lambda_2}{\omega}[\mu(1-\omega^2)C+\rho_I(1-\omega_I^2)I] \tag{E.16}$$

where

$$F=(C(1-h_C))^{(1-\varrho)(1-\sigma)-1}(1-L)^{\varrho(1-\sigma)} \tag{E.17}$$

Also define

$$F_1=(C(1-h_C))^{(1-\varrho)(1-\sigma)}(1-L)^{\varrho(1-\sigma)}=C(1-h_C)F \tag{E.18}$$

Cutting a long story short, one can show that the second order expansion is given by the sum of the following terms

$$\frac{F_1}{2}\left(\frac{(1-\varrho)[(1-\sigma)(1-\varrho)-1](c_t-h_Cc_{t-1})^2}{(1-h_C)^2}-2\frac{(1-\sigma)(1-\varrho)\varrho L(c_t-h_Cc_{t-1})l_t}{(1-h_C)(1-L)}+\frac{\varrho[(1-\sigma)\varrho-1]L^2l_t^2}{(1-L)^2}\right) \tag{E.19}$$

(which is negative definite)

$$\left(\frac{\lambda_2C\mu}{2}[2\omega^3-3\omega+1+\mu\omega(1-\omega)^2]\right.$$
$$\left.+\frac{\lambda_2I\rho_I}{2}[(1-\omega_I)^2(\mu\omega-3\omega-\mu)+1-\omega_I^3+\rho_I(1-3\omega_I^2+2\omega_I^3]\right)\tau_t^2 \tag{E.20}$$

$$\frac{\lambda_2A\alpha(1-\alpha)K^\alpha L^{1-\alpha}}{2}(k_{t-1}-l_t)^2-\lambda_2AK^\alpha L^{1-\alpha}[(1-\alpha)l_t+\alpha k_{t-1}]a_t \tag{E.21}$$

$$\lambda_2(\mu\omega(1-\omega)Cc_t+\mu(1-\omega^*)Cc_t^*+\rho_I\omega_I(1-\omega_I)Ii_t+\rho_I^*(1-\omega_I^*)Ii_t^*)\tau_t \tag{E.22}$$

$$\lambda_2(\mu(1-\omega^2)C+\rho_I(1-\omega^2)I)([(1-\sigma)(1-\varrho)-1]\frac{c_t^*-h_Cc_{t-1}^*}{1-h_C}-(1-\sigma)\varrho\frac{L^*l_t^*}{1-L^*})\tau_t \tag{E.23}$$

Finally, price dispersion arising from price-setting behaviour by firms, and yields a second-order term

$$-\frac{\varrho LF_1}{2(1-L)}\frac{\zeta\xi_H}{(1-\xi_H)(1-\beta\xi_H)}\pi_t^2 \tag{E.24}$$

Finally, we require an expression for λ_2, which is obtained from

$$\lambda_2\left(A(1-\alpha)(\frac{K}{L})^\alpha+\frac{\varrho(1-\sigma)}{\omega(1-L)}[\mu(\omega^2-1)C+\rho_I(\omega_I^2-1)I]\right)=-\frac{\varrho C(1-h_C)F}{1-L} \tag{E.25}$$

If $\sigma>1$, it follows that $\lambda_2<0$. Note too that we may write

$$\lambda_2=-\frac{\varrho c_y(1-h_C)F}{\frac{(1-\alpha)R_K\omega_Ik_y}{\alpha}\frac{1-L}{L}+\frac{\varrho(1-\sigma)}{\omega}[\mu(\omega^2-1)c_y+\rho_I(\omega_I^2-1)i_y]} \tag{E.26}$$

Finally we note that we can divide all terms by FY, and by writing $F_1=FY(1-h_C)c_y$, we can obtain all weights in terms of ratios $c_y, i_y, k_y, \frac{1-L}{L}$ and parameters.

Note that there is an issue here of which values C, L we use in all of these expressions. There is an additional representation of λ_2 for the social planner's problem, which leads ultimately to a linear relationship between C and L, and then via the goods market equation to a complete expression for each of these. One can go through this procedure, or just use the steady state values of observed ratios C/Y, I/Y and G/Y. We choose to do the latter

To obtain the quadratic form, define

$$
\begin{aligned}
cmcl_t &= \frac{c_t - h_C c_{t-1}}{1-h_C} && \text{(E.27)}\\
kml_t &= k_{t-1} - l_t && \text{(E.28)}\\
ccii_t &= \mu\omega(1-\omega)c_y c_t + \mu(1-\omega^*)c_y c_t^* + \rho_I\omega_I(1-\omega_I)i_y i_t + \rho_I^*(1-\omega_I^*)i_y i_t^* && \text{(E.29)}\\
ccsls_t &= [(1-\sigma)(1-\varrho)-1]\frac{c_t^* - h_C c_{t-1}^*}{1-h_C} - (1-\sigma)\varrho\frac{L^* l_t^*}{1-L^*} && \text{(E.30)}
\end{aligned}
$$

Define

$$
\lambda = \frac{\varrho c_y(1-h_C)}{\frac{(1-\alpha)R_K\omega_I k_y}{\alpha}\frac{1-L}{L} + \frac{\varrho(1-\sigma)}{\omega}[\mu(\omega^2-1)c_y + \rho_I(\omega_I^2-1)i_y]} \qquad \text{(E.31)}
$$

Converting the welfare approximation into welfare loss, and dividing by FY leads to

$$
\begin{aligned}
2W &= -(1-h_C)c_y\Bigg((1-\varrho)[(1-\sigma)(1-\varrho)-1]cmcl_t^2 \qquad \text{(E.32)}\\
&\quad -2(1-\sigma)\varrho(1-\varrho)cmcl_t\frac{Ll_t}{1-L} + \frac{\varrho[(1-\sigma)\varrho-1]L^2 l_t^2}{(1-L)^2}\Bigg)\\
&- \Bigg(\lambda c_y\mu[2\omega^3 - 3\omega + 1 + \mu\omega(1-\omega)^2]\\
&\quad + \frac{\lambda i_y\rho_I}{2}[(1-\omega_I)^2(\mu\omega - 3\omega - \mu) + 1 - \omega_I^3 + \rho_I(1 - 3\omega_I^2 + 2\omega_I^3]\Bigg)\tau_t^2\\
&- \lambda\frac{\Phi+Y}{Y}\alpha(1-\alpha)kml_t^2 + 2\lambda\frac{\Phi+Y}{Y}y_t a_t - 2\lambda ccii_t\tau_t - 2\lambda ccsls_t\tau_t + \frac{\varrho L(1-h_C)}{(1-L)}\frac{\zeta\xi_H}{(1-\xi_H)(1-\beta\xi_H)}\pi_t^2
\end{aligned}
$$

which corresponds to (62) in the main text.

The change in welfare for a small change in consumption-equivalent over all periods is given by

$$
\begin{aligned}
\Delta\Omega &= (1-\rho)\sum_{t=0}^{\infty}\beta^t C(1-h_C)^{(1-\sigma)(1-\rho)-1}(1-L)^{\rho(1-\sigma)}(\Delta C - h_C\Delta C)\\
&= \frac{(1-\rho)(1-h_C)c_y}{1-\beta}FYc_e \qquad \text{(E.33)}
\end{aligned}
$$

Ignoring the term in $FY = C(1-h_C)^{(1-\sigma)(1-\rho)-1}(1-L)^{\rho(1-\sigma)}Y$, since all the welfare loss terms have been normalised by this, we can rewrite this as

$$
c_e = \frac{(1-\beta)\Delta\Omega}{(1-\rho)(1-h_C)c_y} \qquad \text{(E.34)}
$$

Furthermore, if all welfare loss terms have been further normalized by $(1-\beta)$, and that all variances are expressed in $\%^2$, it follows that we can write c_e in % terms as

$$
c_e = \frac{\Delta\Omega}{(1-\rho)(1-h_C)c_y}\times 10^{-2} \qquad \text{(E.35)}
$$

which corresponds to (66) in the main text.

	I	II ($a = 0.5$)	III	IV ($\varphi = 0.5$)
a_t	0.8100	0.7779	0.6642	0.6980
g_t	0.0438	0.0416	0.0417	0.0475
g_t^*	0.0010	0.0001	0.0046	0.0046
$\epsilon_{UIP,t}$	0.0567	0.0520	0.0884	0.0863
$\epsilon_{R,t}^*$	0.0543	0.0240	0.0681	0.1406
$\epsilon_{P,t}$	0.0196	0.0197	0.1731	0.5970
ALL SHOCKS	0.9855	0.9152	1.0400	1.5742

Table 1: Expected Welfare Loss Decomposition.

	I	II ($a = 0.5$)	II ($a = 0$)	III	IV ($\varphi = 0.75$)	IV ($\varphi = 0.5$)	IV($\varphi = 0$)	V ($a = \varphi = 0.5$)
var(y_t)	4.50	4.53	4.31	13.3	13.1	17.5	25.6	17.8
var(c_t)	0.89	0.94	0.95	1.36	1.48	2.37	4.23	2.58
var(i_t)	9.67	9.78	9.72	139	117	138	44.2	135
var(q_t^k)	11.9	12.0	11.8	12.8	12.9	13.2	7.66	13.1
var(l_t)	0.72	0.58	0.39	1.19	1.22	1.83	30.3	1.61
var(rer_t)	3.66	3.61	3.54	3.82	4.33	5.89	16.9	5.68
var($\pi_{H,t}$)	0.03	0.03	0.01	0.03	0.03	0.03	1.59	0.03
var(π_t)	0.26	0.29	0.42	0.31	0.41	0.63	5.88	0.63
var($r_{n,t}$)	1.24	1.37	1.81	1.37	1.93	4.13	19.2	4.17
var(n_t)	0	0	0	227	207	274	118	270
var(θ_t)	1.33	1.33	1.33	2.02	2.03	2.19	1.67	2.18
var(Δy_t)	2.08	2.21	2.60	2.47	2.60	3.16	13.31	3.18
Ω_0	0.986	0.915	0.778	1.040	1.156	1.574	19.14	1.466

Table 2: Variances in $\%^2$ and Expected Welfare Loss.

Rule	ρ	θ_π	θ_y	θ_s
FLEX(D): Model I	1.0	5.0	0.32	0
FLEX(C): Model I	1.0	5.0	0.016	0
HYB: Model I	1.0	5.0	0.29	0.025
FLEX(D): Model II	1.0	5.0	0.25	0
FLEX(C): Model II	0.82	5.0	0.016	0
HYB: Model II	1.0	5.0	0.22	0.03
FLEX(D): Model III	0.95	5.0	0.44	0
FLEX(C): Model III	0.62	5.0	0.011	0
HYB: Model III	0.95	5.0	0.44	0
FLEX(D): Model IV	0.91	5.0	0.34	0
FLEX(C): Model IV	0.72	5.0	0.069	0
HYB: Model IV	0.91	5.0	0.34	0

Table 3. Optimized Rules

Rule	var(y_t)	var(c_t)	var(i_t)	var(q_t^k)	var(rer_t)	var($\pi_{H,t}$)	var(π_t)	var($r_{n,t}$)	var(θ_t)	Ω_0	c_e(%)
FIX	1.42	0.46	11.4	9.20	0.83	1.31	1.21	3.02	1.33	9.74	0.50
FLEX(D)	4.47	0.78	9.57	10.6	3.75	0.03	0.31	1.01	1.33	1.05	0.004
FLEX(C)	2.02	0.53	9.41	8.82	7.51	0.12	0.02	0.76	1.33	1.59	0.03
HYB	4.44	0.78	9.58	10.6	3.72	0.03	0.30	1.01	1.33	1.05	0.003
Optimal	4.50	0.89	9.67	11.9	3.66	0.03	0.26	1.24	1.33	0.986	0

Table 4. Outcome of Rules in Model I (No TD, No FA)

Rule	$\text{var}(y_t)$	$\text{var}(c_t)$	$\text{var}(i_t)$	$\text{var}(q_t^k)$	$\text{var}(rer_t)$	$\text{var}(\pi_{H,t})$	$\text{var}(\pi_t)$	$\text{var}(r_{n,t})$	$\text{var}(\theta_t)$	Ω_0	$c_e(\%)$
FIX	1.64	0.57	11.5	9.54	0.89	1.25	1.17	3.43	1.33	9.324	0.48
FLEX(D)	4.49	0.86	9.76	10.8	3.66	0.03	0.33	1.00	1.33	0.977	0.004
FLEX(C)	3.11	0.74	9.67	8.78	2.32	0.06	0.06	0.96	1.33	1.09	0.01
HYB	4.48	0.86	9.77	10.8	3.64	0.03	0.33	1.00	1.33	0.976	0.004
Optimal	4.53	0.94	9.78	12.0	3.61	0.03	0.29	1.37	1.33	0.915	0

Table 5. Outcome of Rules in Model II (TD Only)

Rule	$\text{var}(y_t)$	$\text{var}(c_t)$	$\text{var}(i_t)$	$\text{var}(q_t^k)$	$\text{var}(rer_t)$	$\text{var}(\pi_{H,t})$	$\text{var}(\pi_t)$	$\text{var}(r_{n,t})$	$\text{var}(\theta_t)$	Ω_0	$c_e(\%)$
FIX	57.7	54.3	977	61.3	10.9	2.19	1.59	9.83	5.96	19.8	1.07
FLEX(D)	17.5	1.76	217	15.9	4.62	0.03	0.23	1.60	2.56	1.24	0.01
FLEX(C)	22.1	2.27	347	29.1	5.63	0.17	0.03	3.07	3.36	2.94	0.101
HYB	17.5	1.76	217	15.9	4.62	0.03	0.23	1.60	2.56	1.24	0.01
Optimal	13.3	1.36	139	12.8	3.82	0.03	0.31	1.37	2.02	1.04	0

Table 6. Outcome of Rules in Model III (FA, No TD)

Rule	$\text{var}(y_t)$	$\text{var}(c_t)$	$\text{var}(i_t)$	$\text{var}(q_t^k)$	$\text{var}(rer_t)$	$\text{var}(\pi_{H,t})$	$\text{var}(\pi_t)$	$\text{var}(r_{n,t})$	$\text{var}(\theta_t)$	Ω_0	$c_e(\%)$
FIX	91.2	10.2	1343	72.8	16.0	2.41	1.70	17.6	11.3	22.9	1.25
FLEX(D)	20.6	2.30	232	16.6	5.64	0.03	0.28	2.75	3.46	1.48	0.019
FLEX(C)	32.3	3.72	451	33.2	7.62	0.21	0.03	5.63	3.85	3.81	0.15
HYB	20.6	2.30	232	16.6	5.64	0.03	0.28	2.75	3.46	1.48	0.019
Optimal	13.1	1.48	117	12.9	4.33	0.03	0.41	1.93	2.03	1.16	0

Table 7. Outcome of Rules in Model IV (FA, LD ($\varphi = 0.75$), no TD)

w_r	σ_r^2	$\tilde{\Omega}_0(w_r)$	$\tilde{\Omega}_0(0)$	π^*	$\bar{\Omega}_0(0)$	$\Omega_0(0)$
0	1.93	1.156	1.156	0.46	0.476	1.632
0.1	1.72	1.231	1.160	0.22	0.109	1.269
0.2	**1.58**	**1.300**	**1.169**	**0.06**	**0.008**	**1.177**
0.3	1.47	1.363	1.181	0	0	1.181
0.4	1.38	1.422	1.194	0	0	1.194

Table 8. Optimal Commitment with a Nominal Interest Rate ZLB. Model IV with $\varphi = 0.75$

Notation: $\pi^* = \max[z_0(p)\sigma_r - (\frac{1}{\beta(1+g_{u_c})} - 1) \times 100, 0] = \max[3.00\sigma_r - 3.71, 0]$ with $p = 0.001$ probability of hitting the zero-lower bound and $\beta = 0.99$, $g_{u_c} = -0.26$. $\bar{\Omega}_0(0) = \frac{1}{2} w_\pi \pi^{*2} = 2.248\pi^{*2}$. $\Omega_0(0) = \tilde{\Omega}_0(0) + \bar{\Omega}_0(0)$.

w_r	$[\rho, \theta_\pi, \theta_{\Delta y}]$	$\text{var}(r_{n,t})$	$\tilde{\Omega}_0(w_r)$	$\tilde{\Omega}_0(0)$	π^*	$\bar{\Omega}_0(0)$	$\Omega_0(0)$
0	[0.91 5.0 0.39]	2.75	1.48	1.48	2.53	14.39	15.87
0.5	[1.0 5.0 0.54]	2.52	1.98	1.49	2.32	12.10	13.59
1	[1.0 5.0 0.64]	2.44	2.47	1.51	2.25	11.38	12.89
2	[1.0 5.0 0.78]	2.36	3.40	1.55	2.17	10.59	12.14
3	[1.0 5.0 0.87]	2.32	4.32	1.59	2.13	10.20	11.79
4	[1.0 5.0 0.94]	2.30	5.22	1.61	2.11	10.01	11.62
5	[1.0 5.0 0.99]	2.28	6.13	1.63	2.09	9.82	11.45
10	[1.0 5.0 1.13]	2.26	10.6	1.70	2.07	9.63	11.33
20	**[1.0 5.0 1.24]**	**2.24**	**19.48**	**1.75**	**2.05**	**9.45**	**11.20**
50	[1.0 5.0 1.34]	2.24	46.02	1.80	2.05	9.45	11.25

Table 9a. Optimal FLEX (D) Rule with a Nominal Interest Rate ZLB. Model IV

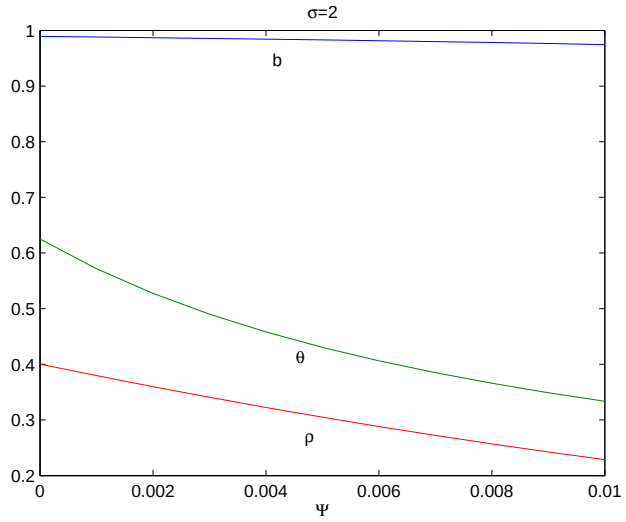
w_r	$[\rho, \theta_\pi, \theta_{\Delta y}]$	$\text{var}(r_{n,t})$	$\tilde{\Omega}_0(w_r)$	$\tilde{\Omega}_0(0)$	π^*	$\bar{\Omega}_0(0)$	$\Omega_0(0)$
0	[0.0 19.90 1.066]	5.21	3.67	3.67	3.14	22.16	25.83
5	[1.0 15.66 5.0]	4.04	11.73	3.99	2.32	12.10	16.09
10	[1.0 12.48 5.0]	3.99	19.38	4.15	2.28	11.68	15.83
15	**[1.0 11.27 5.0]**	**3.97**	**26.96**	**4.24**	**2.27**	**11.58**	**15.82**
20	[1.0 10.61 5.0]	3.97	34.43	4.30	2.27	11.58	15.88

Table 9b. Optimal FLEX (C) Rule with a Nominal Interest Rate ZLB. Model IV

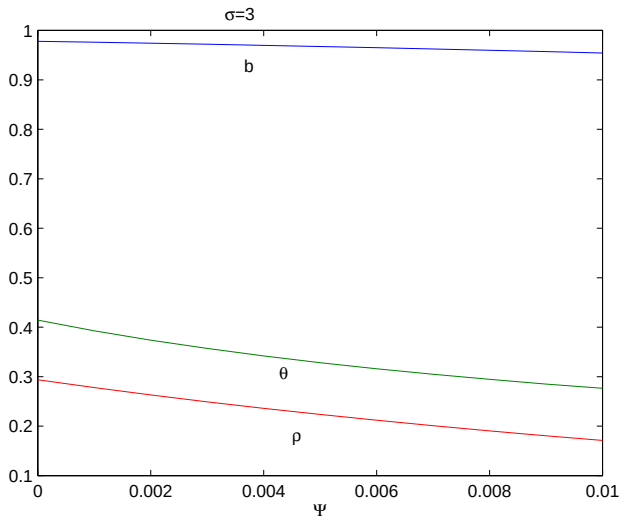
Rule	var($r_{n,t}$)	π^*	$\tilde{\Omega}_0(0)$	$\bar{\Omega}_0(0)$	$\Omega_0(0)$	c_e (%)
FIX	17.6	8.88	22.9	177	200	11.4
FLEX(D)	2.24	2.05	1.75	9.45	11.2	0.57
FLEX(C)	3.97	2.27	4.24	11.58	11.82	0.83
Optimal	1.58	0.06	1.17	0.01	1.18	0

Table 10. Summary of Welfare Outcome of Rules with a Nominal Interest Rate ZLB Imposed. Model IV

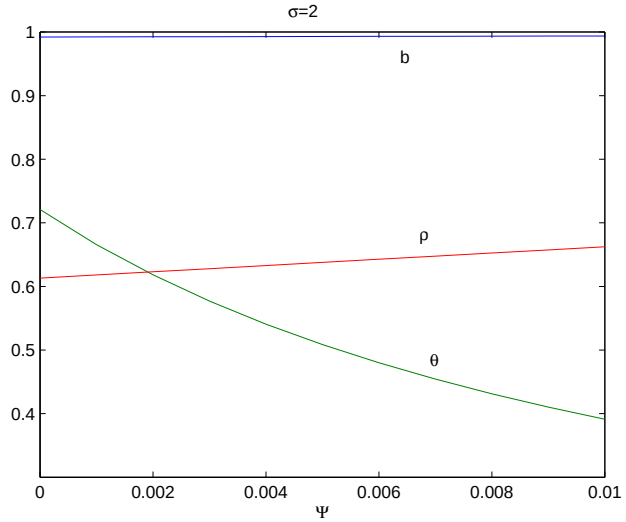
Note: c_e is the consumption equivalent welfare loss compared with the optimal policy given by $c_e = \frac{\Omega^i(0)-\Omega^{OPT}(0)}{(1-\varrho)(1-h_C)c_y} \times 10^{-2}$, $i =$ FE, Taylor.



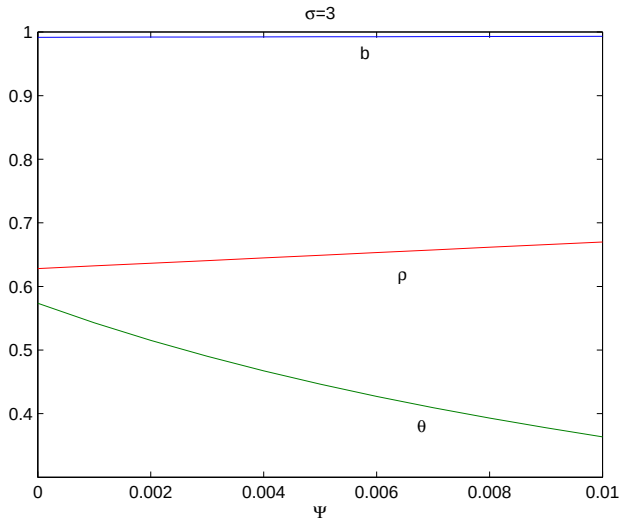
(a) Peru: $\sigma = 2$



(b) Peru: $\sigma = 3$



(c) US: $\sigma = 2$



(d) US: $\sigma = 3$

Figure 1: **Calibration of Preference Parameters**

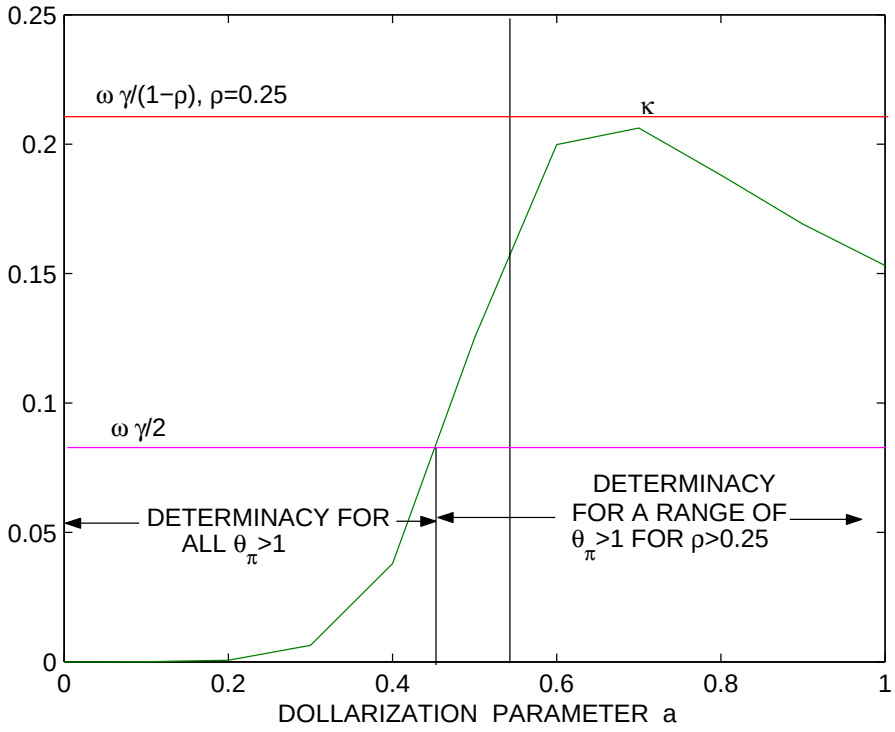


Figure 2: **Transactions Dollarization and Determinacy of Current Inflation Rule**

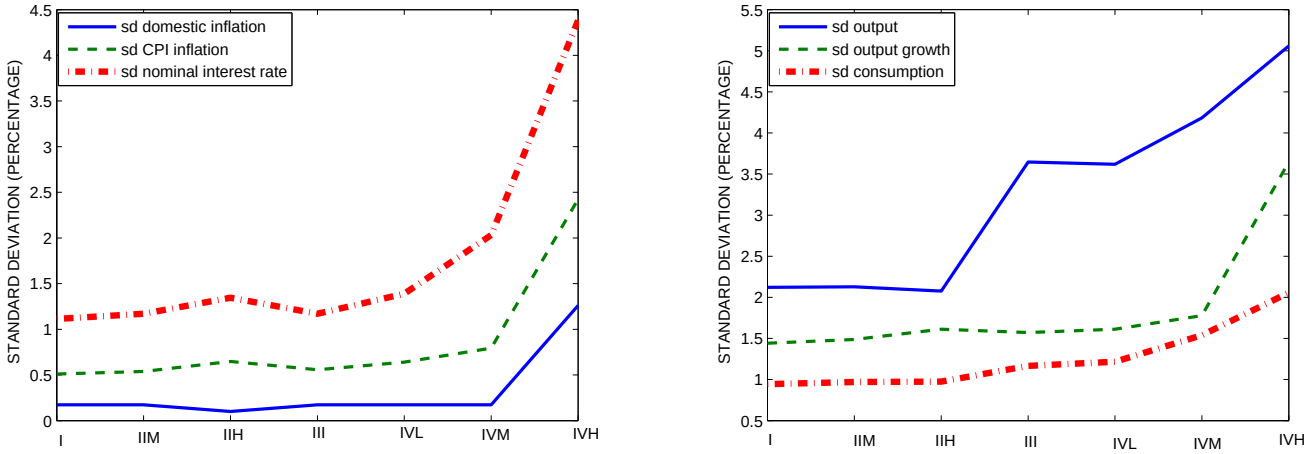


Figure 3: **Standard Deviations of Key Variables**

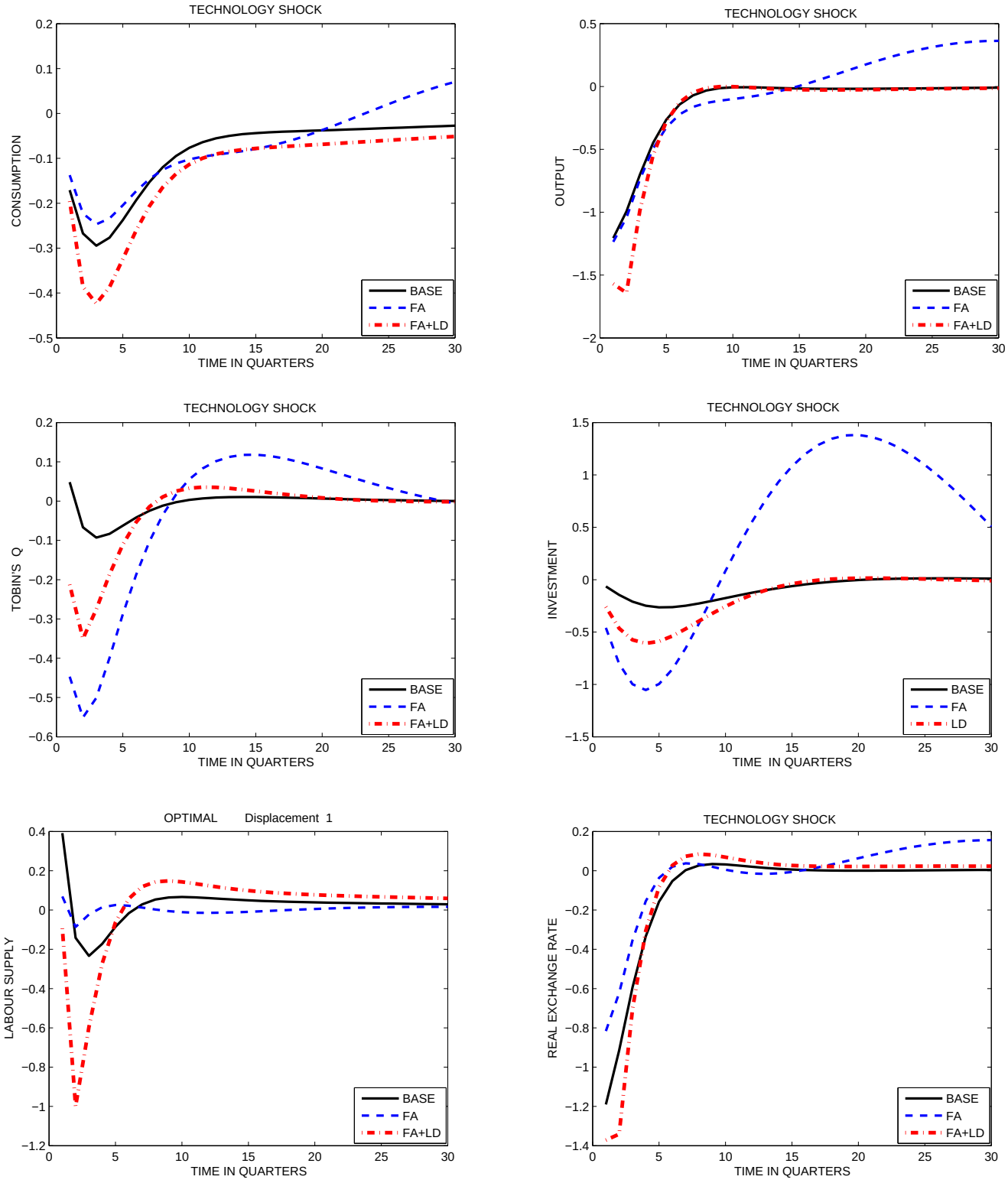


Figure 4: **Responses to a Technology Shock under Optimal Monetary Policy**

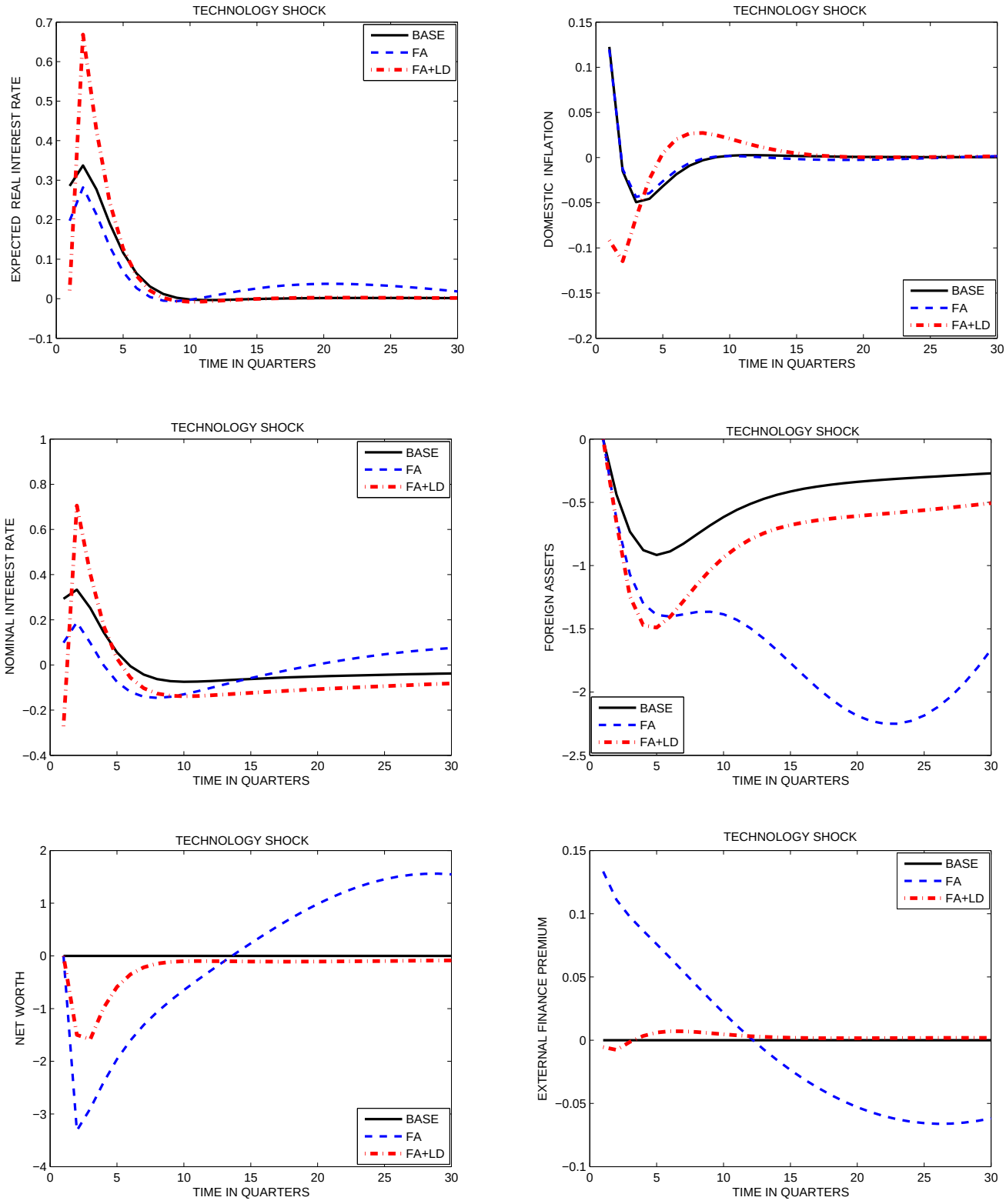


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Figure 5: **Responses to a Technology Shock under Optimal Monetary Policy**

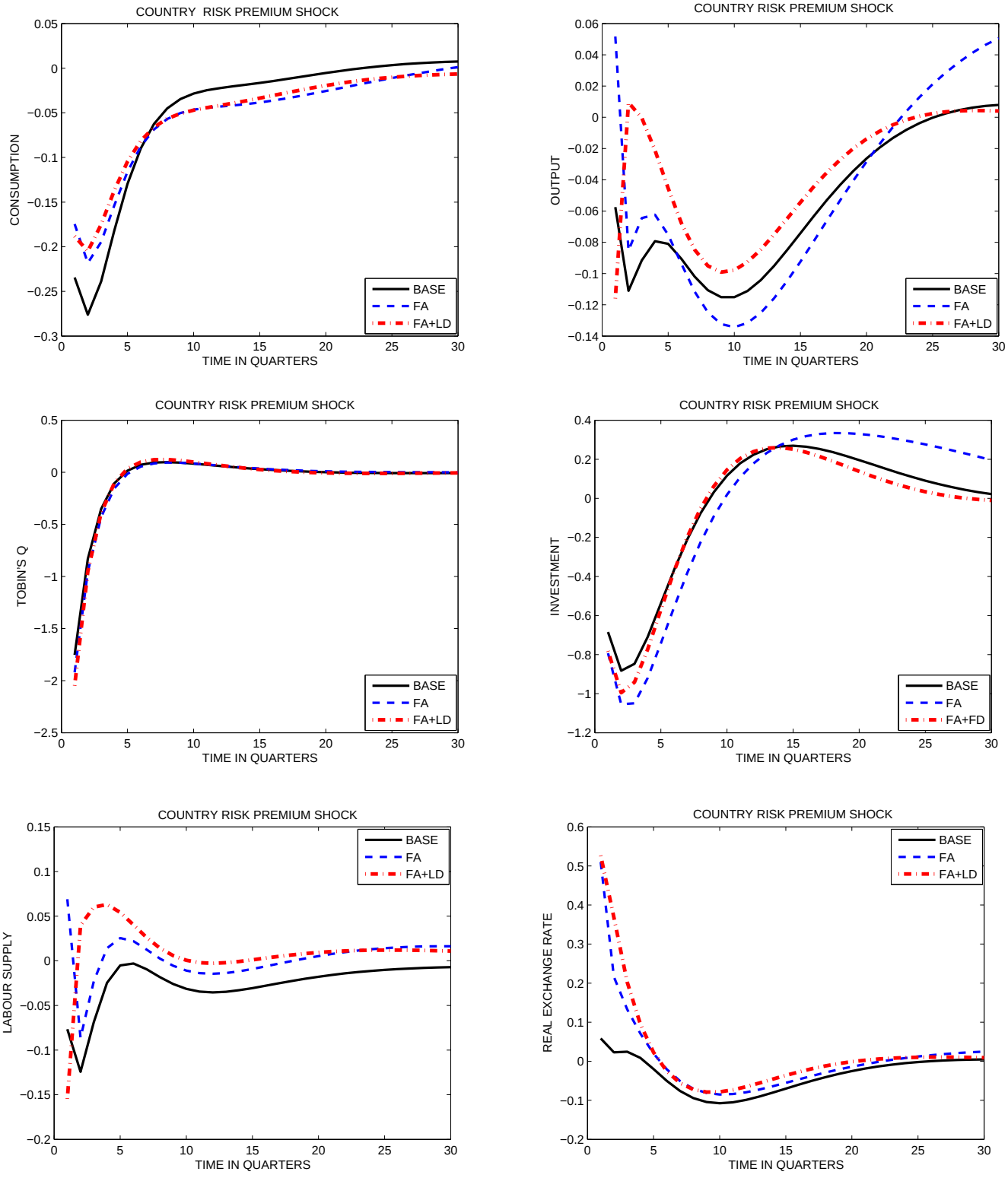

Figure 6: **Responses to a UIP Shock under Optimal Monetary Policy**

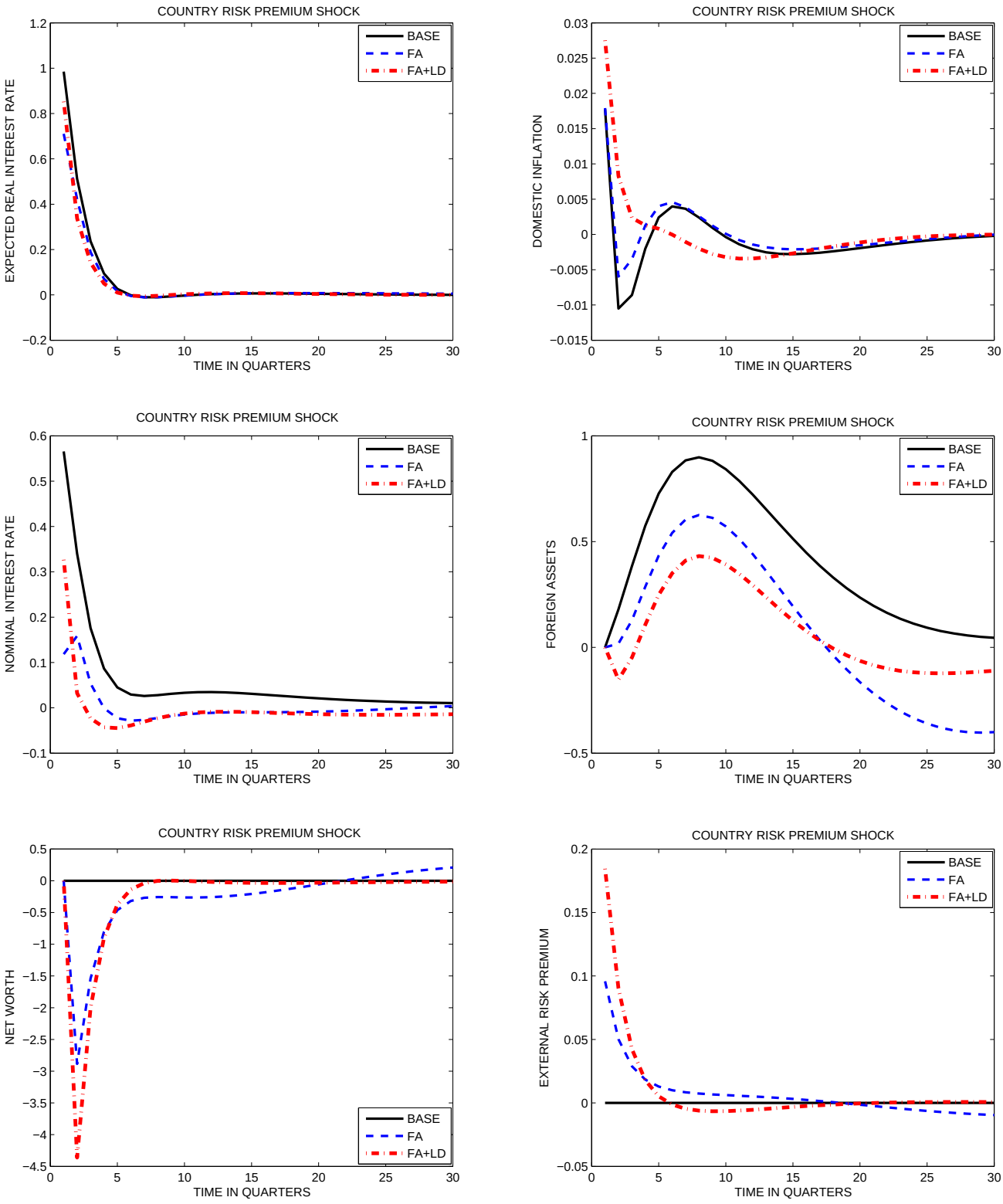

Figure 7: **Responses to a UIP Shock under Optimal Monetary Policy**