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RESEARCH ARTICLE

Modeling Sterilized Interventions and Balance Sheet Effects of Monetary Policy in a New-Keynesian Framework

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Abstract We study a wide range of hybrid inflation–targeting (IT) and managed exchange rate regimes, analyzing their implications for inflation, output and the exchange rate. To this end, we develop an open economy new–Keynesian model featuring sterilized interventions as an additional central bank instrument operating alongside the Taylor rule and affecting the economy through portfolio balance effects in the financial sector. We find that there can be advantages, from a welfare perspective, to combining IT with some degree of exchange rate management via FX interventions. Unlike "pure" IT or exchange rate management via interest rates, FX interventions can help insulate the economy against certain shocks, especially shocks to international financial conditions. However, managing the exchange rate through interventions may also hinder necessary exchange rate adjustments, e.g., in the presence of terms of trade shocks.

Keywords Sterilized FX interventions · Balance sheet effects · Monetary policy · Emerging markets · New-Keynesian framework

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1 Introduction

Monetary policy is defined by the objectives, targets and instruments that both guide and characterize the behavior of central banks. Until recently, a typical summary of monetary policy would list price stability as the main policy objective, inflation (or the exchange rate or monetary aggregates in some cases) as the intermediate target, and short term interest rate as the sole instrument. The above view was also reflected in the standard macroeconomic model, the new-Keynesian framework, which typically models policy as a rule in which interest rates respond to deviations of inflation from its target.

Following the global financial crisis and the policy responses that have been implemented in advanced economies, it has become increasingly clear that such a simple characterization of monetary policy misses some of the main instruments and channels through which central banks have attempted to influence economic activity, especially when interest rates are stuck at the zero lower bound.[1] What is less clear, at least in the academic literature, is that monetary policy in emerging markets is also considerably richer than what is described in the simple new-Keynesian framework, but for reasons that are unrelated to the zero lower bound and crisis episodes. The key missing element in policy analysis in emerging markets is the FX intervention policy of the central bank.

Foreign exchange (FX) interventions have always been an important component of central bank policy in emerging and developing economies. Beyond the accumulation of reserves to achieve a desired level, several surveys covering a large number of emerging markets (EM) document a wide recourse to interventions to limit exchange rate volatility or protect competitiveness ((BIS 2005) and (IMF 2011), among others). This is clearly observed in the last few years, both pre– and post–crisis. EMs employed massive interventions to dampen currency appreciation during 2007–mid 2008 (Adler and Tovar 2011). Later, when emerging currencies came under selling pressure, many central banks sold FX to control the speed of depreciation. In 2010—with a gradual return of capital inflows to emerging markets—central banks once again started accumulating FX reserves.[2] In addition, many of the emerging markets

[1] See Curdia and Woodford (2011), and Gertler and Karadi (2011) for a modelling of the credit policy of the central bank.

[2] Even central banks in several developed countries (including Switzerland, Australia, and Israel, among others) embarked on regular interventions, as a part of their efforts to stabilize domestic financial conditions. See Reserve (Reserve Bank of Australia 2008), (Bank of Israel 2009), and (Swiss National Bank 2008).

that intervene in their FX market also steer short–term interest rates to influence economic activity and communicate policy.

The main contribution of this paper is the extension of a standard inflation targeting New-Keynesian small–open–economy model to include FX interventions as an independent central bank instrument. Our framework adds to the standard New Keynesian model: (i) a rule for FX interventions operating alongside interest rate policy; (ii) balance sheets effects of intervention policies, and (iii) the possible coexistence of interest–rate–based inflation targeting with a managed float or a fixed exchange rate.

We focus on sterilized interventions, i.e., purchases of FX reserves that involve an offsetting operation, e.g., an issuance of central bank securities, such that the short-term interest rate is not affected (all else equal). For sterilized interventions to serve as a separate instrument of monetary policy, alongside interest rate policy, they must operate through a different channel. The independent channel through which interventions operate stems from the portfolio approach to exchange rate determination.

The intuition is the following. A sterilized intervention, in which the central bank issues a security to fund the purchase of FX reserves, increases the holdings of local–currency–denominated assets by the domestic financial system. Holding net foreign liabilities constant, the increase in reserves requires an increase in the country's external borrowing (or a reduction in external assets), which in our model takes place through an increase in the foreign–currency–denominated liabilities of the financial sector. As a result of the sterilized intervention, the financial system's exposure to exchange rate risk has therefore increased, which leads to an increase in the risk premia required for banks to hold domestic assets. Since the central bank controls short term rates, the higher risk premia must manifest itself in a more depreciated nominal (and hence real) exchange rate. Note that this channel is different from the traditional interest rate channel of monetary policy, which depends crucially on the degree of nominal rigidities in the economy. The effectiveness of sterilized interventions depend instead on the degree to which they can influence risk premia.

The existence of multiple instruments (interventions, interest rates) and channels increases the range of central bank policy, e.g., it allows for the combination of inflation targeting (IT) regimes with some degree of exchange rate management. The former can be implemented via interest rates and the latter via interventions. We use our expanded framework to study these hybrid regimes, relative to standard frameworks (pure IT, interest–rate–based pegs), and focus on two external shocks: shocks to international financial conditions and shocks to the terms of trade. We also assess the implications of these regimes for welfare.

We find that there can be advantages to hybrid regimes, though much depends on the types of shocks, and the strength (and specific modeling) of the balance sheet effects. For instance, in the case of a shock to foreign interest rates, we illustrate the contrasting performance of exchange rate pegs maintained by interest rates and by interventions. In the former case, monetary policy has to follow foreign interest rates in order to keep the exchange rate unchanged, which has strong and negative implications for the rest of the economy. In the latter, FX interventions can potentially insulate the domestic interest rates from such pressures by acting instead on the interest rate wedge in the financial system. This insulating property makes hybrid regimes superior to the other regimes we consider, including pure forms of inflation targeting in which the authorities do not intervene.

In the case of shocks to the terms of trade however, intervention policies can be counterproductive if they delay the necessary nominal and real exchange rate adjustment. Output will be more volatile as a result, and welfare will be lower. This is more likely to be the case with policies that target a nominal exchange rate level, as opposed to intervention policies that attempt to reduce exchange rate volatility ("leaning against the wind"). In addition, the costs of delaying adjustment increases as terms of trade shocks have more persistent effects. Much of the challenge of intervention policy is therefore to understand the nature of the (external) shocks facing the economy.

From a modeling perspective, an important insight from our analysis is that it matters a great deal whether sterilized interventions affect premia on all domestic assets (including the rates that matter for private sector decisions such as lending rates) or only the premia of government/central bank debt. In the latter case, interventions will lose their effectiveness, e.g., in the case of a foreign interest rate shock, since they cannot insulate domestic lending conditions from external financial conditions.

While we believe our paper is the first to formalize the use of FX intervention alongside standard monetary policy rules in a new-Keynesian framework, it coincides with recent work by Ostry et al. (2012). These authors also argue that monetary policy in emerging markets is best characterized as having two targets (inflation and exchange rates) and two instruments (shortterm interest rates and sterilized FX interventions), and that such regimes are preferable when deviations of exchange rates from medium run values are costly.

The rest of the paper is organized as follows. The next section describes the pitfalls of standard approaches to modeling exchange rate targeting by central banks. We then introduce our model. We illustrate and contrast various exchange rate/monetary policy regimes using model simulations, including by assessing performance from a welfare perspective, and discuss limits of intervention policy. The final section concludes.

2 Exchange Rate Targeting and Exchange Rate Intervention: Two Unrelated Literatures

2.1 The Exchange Rate Targeting Literature

Much of the literature on the role of the exchange rate in monetary policy is concerned with investigating "dirty" inflation targeting—a combination of inflation targeting with some degree of exchange rate targeting. The focus is typically on whether including the exchange rate in the interest rate rule helps achieve better macroeconomic outcomes (Taylor 2001; Natalucci and Ravenna 2002), and (Roger et al. 2009).

While there is little theoretical support for targeting the exchange rate in developed economies, the situation is somewhat more complex for emerging markets. Several features of emerging markets have been analyzed: financially vulnerable or dollarized economies (Morn and Winkelried 2005; Batini et al. 2007), uncertainty about the policy transmission (Leitemo and Sderstrm 2005), the role of policy credibility and expectations formation (Roger et al. 2009), or structural features such as high productivity growth or limited recourse to inter-temporal substitution (Natalucci and Ravenna 2002) and (Roger et al. 2009).

Despite these complications the literature finds limited support for targeting the exchange rate, and emphasizes the significant risks involved. For instance, (Roger et al. 2009) conclude that having the exchange rate in the interest rate rule may reduce the volatility of the exchange rate, the interest rate, and the trade balance, but at the cost of higher inflation and output volatility, especially if the economy is exposed to demand and cost–push shocks. They also note that any benefits tend to disappear with high degrees of exchange rate targeting.

Monetary policy is modeled in this literature as follows:

$$i = \bar{i} + \alpha\left(\pi - \pi^T\right) + \delta\hat{y} + \chi\Upsilon, \tag{1}$$

where i denotes the nominal interest rate, $\bar{i}$ is the neutral or natural level of the former, π is the rate of inflation and $\hat{y}$ is the output gap in percent of trend or potential output.[3] The superscript T denotes a target level for that variable. The term Υ specifies exchange rate targeting behavior. It can have a number of functional forms; (Roger et al. 2009) cast it in real terms as:

$$\Upsilon = log(q) - \eta log(q_{-1}),$$

where q is the real exchange rate (the price of the foreign consumption basket relative to the domestic consumption basket). The real exchange rate is defined as $q = P^*S/P$, where S is the nominal exchange rate (the local currency price of foreign currency), and (P^*, P) denote the foreign and domestic price levels, respectively. The addition of Υ to the standard Taylor rule allows a response to real exchange rate “misalignments” (when $\eta = 0$), as well as real exchange rate fluctuations (when $\eta = 1$).

Exchange rate targeting can also be cast in nominal terms:

$$\Upsilon = \eta log(S/S_{-1}) + (1-\eta)\, log(S/S^T). \tag{2}$$

[3]Uppercase variables denote nominal variables in levels, while lowercase variables denote real variables or nominal rates such as inflation and interest rates.A ’hat’ ($\hat{*}$) denotes a log-deviation from the steady state.

Less flexible exchange rate regimes are represented by a high χ and small η, as in (Parrado 2004a) or (Natalucci and Ravenna 2002).[4]

These approaches are unsatisfactory for several reasons:

- Sterilized interventions are the main instrument used by many emerging market central banks to affect the exchange rate. While some central banks may have explicit exchange rate objectives in mind when setting interest rates, that is not their main—or at least their only—instrument for influencing the exchange rate.
- In these models, including the exchange rate in the Taylor rule reduces the central bank autonomy in setting the interest rate. In the extreme case, fixing the exchange rate through the Taylor rule implies the interest rate becomes exogenous to domestic developments.[5] For instance, setting χ in (2) to infinity makes the Taylor rule collapse to $S = S^T$, and the interest rate is then determined through the uncovered interest rate parity (UIP) condition. By contrast, in practice many central banks manage exchange rates precisely to increase their autonomy and room for policy maneuvering.
- It is clear that central banks resorting to exchange rate management hope to engage different transmission channels working through balance sheet effects and FX liquidity, and potentially also to target several objectives simultaneously (BIS 2005). Yet in the standard models, the interest rates affect the economy, as usual, by influencing the nominal exchange rate (through UIP) and the consumption/investment behavior of the private sector (through the Euler equation). There is no separate transmission channel involved in exchange rate targeting.

A few authors introduce a separate explicit rule for the exchange rate directly into their models. For instance, (Parrado 2004b)—in his analysis of monetary policy in Singapore—suggests replacing the interest rate rule by a rule specified directly in terms of the exchange rate:

$$log(S) = \rho log(S_{-1}) - (1-\rho)\left(\alpha(\pi - \pi^T) + \delta\hat{y}\right).$$

As with the previous specification however, this approach leaves the interest rates to be determined by external developments via the UIP condition.

2.2 The FX Intervention Literature

The large literature on sterilized interventions mostly predates the new–Keynesian models used to analyze inflation targeting in recent years. The portfolio–balance approach to exchange rate determination (Kouri 1976; Henderson and Rogoff 1982) embraced a potentially important role for sterilized intervention to affect

[4] A properly defined steady state requires perfect consistency between nominal targets. In the absence of a trend in the real exchange rate, so that the equilibrium real exchange rate is $\overline{q}$, π^T and S^T must satisfy the following identity: $log(S^T/S^T_{-1}) = log(\overline{q}/\overline{q}) + log((P/P_{-1})^T) - log((P^*/P^*_{-1})^T) = \pi^T - \pi^{*T}$.

[5] The interest rate reflects domestic shocks only to the extent that the country's external risk premium responds endogenously to these shocks, e.g., by being sensitive to movements in the current account or in the country's net foreign asset position.

the exchange rate, by allowing changes in the asset composition of portfolios to influence risk premia. This strand of work in open economy macroeconomics generally lost out to the assumption of perfect asset substitutability, going back to Dornbusch (1976).[6]

One reason why the portfolio balance approach fell out of favor was the difficulty in micro–founding the link between risk premia and the gross supply of public sector assets, from a general–equilibrium perspective. The strongest critique of sterilized foreign exchange interventions along this line is by Backus and Kehoe (1989): with the help of a general–equilibrium monetary model, they demonstrate that certain types of sterilized interventions—those that hold the time paths of fiscal and standard monetary policy constant—have no effect on private sector decisions (and hence on premia). Interventions that are associated with changes in fiscal and monetary policy do have real effects but not because of the intervention itself.

However, Kumhof (2010) shows that it is theoretically possible to generate imperfect substitutability between various kinds of assets in a general equilibrium setting. He does so by introducing government spending shocks in a small open economy model. These shocks do not elicit a corresponding increase in taxes, ether now or in the future, so that a surprise nominal depreciation (inflation) is required is to clear the government's budget constraint (via seignorage revenue). The exchange rate/inflation volatility that results from these shocks increases the risk to the private sector from holding local currency–denominated government debt. By changing the gross outstanding stock of such debt, sterilized interventions affect the private sector's exposure to exchange rate risk and therefore influence the interest rate premium required in equilibrium to clear asset markets. This mechanism is sufficient for sterilized interventions to affect the exchange rate.

There is a large empirical literature on whether sterilized interventions affect the exchange rate. A constant theme is the fundamental identification problems: the interventions presumably are motivated by events in the exchange rate market, confounding efforts to measure the effects of the interventions per se. Finding good instruments (variables correlated with the propensity to intervene but not with the exchange rate itself) is a serious challenge.

Event studies have in many cases found significant if often small effects. A more recent survey (Cavusoglu 2010) concludes that interventions have a significant but short-lasting effect on exchange rates, with only a few studies looking at the effects on longer movements and few clear results. For advanced economies, (Fatum and Hutchison 2010) find that interventions do indeed affect the exchange rate in Germany and the US, while in the case of Japan (Fatum and Hutchison 2010) find that only sporadic and relatively infrequent interventions are effective. More recent studies have looked at emerging markets. Domac and Mendoza (2004) (Mexico and Turkey), Guimares and Karacadag (2004) (Mexico), Gersl and Holub (2006) (Czech Republic), Egert (2007) (several central and Eastern European countries), and Kamil (2008) (Colombia) find some evidence that sterilized interventions affect the level of the exchange rate; Tuna (2011) (Turkey) find negative results. Adler and Tovar (2011)

[6] Blanchard et al. (2005) propose a revival of the portfolio approach, however.

find some evidence that interventions can affect the pace of appreciation, particularly in countries that have a relatively closed capital account.

Beyond this evidence, we give some weight to the views of many practitioners, particularly in emerging markets and developing countries, that FX interventions can be effective (Neely 2011; BIS 2005); see also Canales-Kriljenko (2003). Particularly for emerging and frontier markets, and a fortiori low–income countries that are just beginning to enter global capital markets, it seems plausible that assets are imperfect substitutes and that markets are relatively "thin", in that changes in supplies can have substantial effects on relative prices. In what follows we examine the implications of these assumptions.

3 The Model

In this section we describe the model. Before proceeding to the optimization problem faced by various agents, it is helpful to provide a broad overview of the sectoral balance sheets, which are summarized below.

Central Bank		Financial Sector		Households	
F	O	O L	B	NS	L

The central bank keeps a stock of FX reserves, F, and issues its own securities, O, held by the financial sector. In addition, the commercial banks provide loans to households, L, and borrow from abroad, B. Borrowing by households is backed by the discounted sum of future expected net savings NS.

All items are expressed in the domestic currency. F and B are denominated in foreign currency, while all the other assets are denominated in domestic currency. The economy is cashless and a net debtor, because the country's net foreign liabilities (the difference between gross foreign debt and gross foreign assets) are equal to the household debt L ($L = B - F$), which is positive.[7]

[7] We chose to use as simplistic balance sheets as allowed by the requirements of our analysis. In doing so, we disregarded many sometimes-important practical aspects, sacrificing realism. For instance, our financial sector runs an unhedged short position in FX, which would not be allowed by prudential regulation. Our households are net borrowers, rather than savers. And we assume a central bank with a negative net domestic asset position, which is a necessary condition if the central bank holds a stock of foreign reserves but does not issue reserve money (in a cashless world). However, our exposition can be generalized. For instance, firms borrowing from the financial sector can be added to make households net savers. The financial sector can run separate balance sheets in FX and local currencies, thus assuming partial financial dollarization. And introducing reserve money can make the net domestic asset position of the central bank positive. For the purposes of our exposition these are unnecessary complications, though. What matters is that sterilized interventions affect the degree of exchange rate risk faced by the domestic financial system, which does not depend on whether the central bank's net domestic assets are positive or negative. In a separate appendix (available upon request) we show how reserve money can be added, but leave the analysis of interventions in the context of financial dollarization for future work.

3.1 Central Bank Behavior

Every period the central bank receives interest on its stock of reserves at an exogenously determined rate i^* (compounded over the period). It pays interest i (also compounded) on the stock of its own securities held by the financial sector (O_{-1}, issued last period) and transfers its cash-flow (CF^{CB}) to households:

$$CF^{CB} = \frac{S}{S_{-1}} F_{-1} \exp(i^*) - O_{-1} \exp(i) - F + O.$$

The central bank decides on the level of reserves and the interest rate it pays on its own securities. The central bank adjusts the stock of FX reserves as follows:

$$\log\left(\frac{F}{P}\right) = \rho_f \log\left(\frac{F}{P}\right)_{-1} + (1-\rho_f)\left(\log\left(\overline{\frac{F}{P}}\right) - \omega \log\left(\frac{S}{S^T}\right) - \vartheta \log\left(\frac{S}{S_{-1}}\right)\right), \quad (3)$$

where $\left(\overline{\frac{F}{P}}\right)$ is the steady state real level of reserves.

If $\omega \to \infty$ the central bank can keep the exchange rate on its target level at all times by instantly adjusting the level of reserves; if $\omega = 0$, it will ignore exchange rate movements and instead keep FX reserves at some desired level. The last term $\vartheta log\left(\frac{S}{S_{-1}}\right)$ captures exchange smoothing behavior—so called "leaning–against–the–wind" interventions, while $\rho_f \log\left(\frac{F}{P}\right)_{-1}$ captures the degree of persistence in reserve movements.

For the sake of simplicity we ignore the lower bound on reserves. We implicitly assume the volume of reserves implied by rule (3) is always positive, or if it entails a negative number, we assume the country can receive external financing, e.g., from official sources like the IMF, for this purpose. We return to the lower bound on reserves in our discussion of the limits of interventions.

The interest rate paid on central bank securities follows an interest rate rule similar to (1):

$$i = \rho i_{-1} + (1-\rho)\left(\bar{i} + \alpha\left(\pi - \pi^T\right) + \delta\hat{y} + \chi\Upsilon\right).$$

where Υ is defined as in (2).

Note that our treatment of central bank instruments is not symmetric: for the exchange rate we track movements in the central bank balance sheet, while for interest rates we do not.[8]

[8] We analyze the balance sheet operations required to implement interest rate policy in a separate appendix (available upon request).This asymmetry reflects central bank practices as well as some underlying economics. Exchange rate targets are analogous to targets on long-term interest rates, in that both imply setting prices for assets that yield capital gains or losses if prices change and hence that are more subject to speculative attacks than overnight rates (see (Woodford 2005) for the case of long rates). This implies that achieving these targets exactly, as represented by an infinite ω in (3) may strain central bank balance sheets and be difficult to achieve. We return to this point later. For current purposes, however, the implication is that many central banks conduct quantity–based operations aimed at achieving targets for the exchange rate without necessarily hitting the targets exactly. Similarly, recent efforts at "quantitative easing' in developed countries aim to influence but not precisely target long interest rates.

3.2 Financial Sector Behavior

The behavior of perfectly competitive financial sector firms (owned by households) is described by the following arbitrage relationships:

$$\exp(i) = \exp(i^*)\frac{S_{+1}}{S}\Omega_O\left(\frac{F}{P}\right),\ \Omega'_O(F/P) > 0 \tag{4}$$

$$\exp(j) = \exp(i) \tag{5}$$

Condition (4) postulates the uncovered interest parity (UIP) condition as an arbitrage between the interest rate on central bank bills and an exchange–rate–adjusted foreign rate, augmented with a spread $\Omega_O(.)$ that is increasing in the stock of FX reserves (deflated by the price level P). As the rate i is defined by the Taylor rule, (4) defines the exchange rate expectations (for a given spread). Condition (5) implies loans and central bank securities are perfect substitutes.

The most important feature is that the UIP spread is *increasing* in the level of reserves (F), which is central to the FX intervention mechanism. As discussed in the introduction, the intuition is that a sterilized intervention increases the stock of local currency assets held by banks ($O + L$) and, all else equal, requires a corresponding increase in foreign borrowing B. This increase in banks balance sheet raises their exposure to exchange rate risk (which is not modeled explicitly), since $O + L$ is denominated in local currency and B is denominated in foreign currency. In the face of this increased exposure, banks will demand a higher return for holding local currency denominated assets. Since $F = O$, it follows that an increase in reserves increases the premium on domestic assets.

This mechanisms merits three remarks. First, the arbitrage conditions in (4, 5) are imposed rather than derived from micro-foundations. They are inspired by the results in (Kumhof 2010) mentioned early.[9] Recent work on two–country general equilibrium models go in a similar direction, though in setups that are different from ours. First, Canzoneri et al. (2013) show how a broadly similar relation can arise when foreign and domestic bonds are imperfect substitutes in each country's transaction's technology. Second, Gabaix and Maggiori (2014) introduce financiers which bear the risks resulting from international imbalances in the demand for financial assets, which then leads them to change their compensation for holding currency risk.

Second, the above argument suggests that the premium should depend on the total stock of domestic assets ($L + O$), as opposed to only the stock of central bank securities (O). This shortcut is not an issue. As will be made clear below, households' financing needs determine the economy's stock of loans L, which implies that

[9] In the working paper version of this paper, we studied whether such a relation could be derived from a simple portfolio allocation problem as well as a a bank cost function that depended on banks' holdings of central bank securities and loans. Although these setups went some way toward generating risk premia that was sensitive to holding of various assets, their functional forms differed considerably from the simple relations presented in the text.

the central bank reserve's policy determines the overall size of the financial sector balance sheet: controlling O is equivalent to controlling $L + O$.[10]

A third and related issue is that the perfect substitutability of the two domestic assets has important consequences. As part of the model simulations we will explore an alternative specification in which loans and foreign assets are perfect substitutes, up to a constant risk premium. This implies replacing (5) with the following:

$$\exp(j) = \exp(i^*)\frac{S_{+1}}{S}\Omega_L$$

Under this specification sterilized interventions will only affect the premia for central bank securities, but will not directly affect the pricing equation for loans. As a result, the premia between loans and central bank securities will vary as a result of the interventions:

$$\exp(j) = \exp(i)\frac{\Omega_L}{\Omega_O(\frac{L}{P})}.$$

3.3 Households Behavior

The household's utility function if of the form $U = ln(c) - \psi(1+\phi)^{-1}n^{1+\phi}$. Agents maximize the expected discounted sum of utility $\left(E_t\left[\sum_{t=0}^{\infty}\beta^t U_t\right]\right)$, over consumption ($c$), labor supply ($n$) and the nominal demand for loans (L), subject to the budget constraint:

$$Pc - L = -\exp(j_{-1})L_{-1} + Wn + CF^{CB} + \pi - P\Psi(L/P),\ \Psi'(L/P) > 0,\ \Psi''(L/P) > 0. \quad (6)$$

W denotes nominal wages, while π is the total amount of profits households receive from the firms and the financial sector. $\Psi(L/P)$ are quadratic adjustment costs, which provide a mechanism for determining the steady state values of real consumption and net foreign assets, similar to other mechanisms in the literature (see Schmitt-Groh and Uribe (2003)).

First order conditions are as follows:

$$\lambda P = \frac{1}{c},$$

$$\psi n^{\phi} = \frac{W}{P}\frac{1}{c} = \frac{w}{c},$$

$$\lambda\left(1 - \varrho(\frac{L}{P})\right) = \beta e^j E[\lambda_{+1}],$$

where λ is the Lagrange multiplier associated with the budget constraint, and $\varrho(L/P) = \Psi'(L/P)$ introduces a credit sensitive wedge between the interest and

[10] If the premium depends on the total stock of domestic assets, then the intervention rule in (3) can be specified in terms of $L + O$, and the model–based analysis would be the same.

the discount factor in the Euler condition. Consumption is an aggregate of non–traded goods c_n and imports c_m:

$$c = Ac_n^{\omega_n} c_m^{1-\omega_n},$$

where ω_n is the weight on non–traded goods, and $A = {\omega_n}^{-\omega_n}(1-\omega_n)^{-(1-\omega_n)}$. Cost minimization results in the following demand functions:

$$c_n = \omega_n \left(\frac{P_n}{P}\right)^{-1} c = \omega_n {p_n}^{-1} c,\, c_m = (1-\omega_n)\left(\frac{P_m}{P}\right)^{-1} c = (1-\omega_n){p_m}^{-1} c.$$

P_n and P_m denote prices for C_n and C_m, respectively, with $P = {P_n}^{\omega_n}{P_m}^{(1-\omega_n)}$. p_n and p_m denote relative prices (deflated by the CPI), with ${p_n}^{\omega_n}{p_m}^{(1-\omega_n)} = 1$.

CPI inflation π is given by:

$$\pi = \omega_n\,(log(P_n) - log(P_{n-1})) + (1-\omega_n)\,(log(P_m) - log(P_{m-1})) = \omega_n \pi_n + (1-\omega_n)\,\pi_m \quad (7)$$

3.4 Non–traded Producers

There is a continuum of firms in the non–traded sector, each having a monopoly on the production of a variety of the non–traded good and facing a demand curve with elasticity $\varpi = \mu/(1-\mu)$. Firms hire labor to produce their good, with a production function that has decreasing returns to scale, and benefit from an employment subsidy ι. Cost minimization results in the following labor demand condition:

$$\gamma MC_n c_n = n_n W(1-\iota) \longleftrightarrow \gamma mc_n c_n = n_n w(1-\iota)$$

where γ is labor share in the non–traded sector, MC_n (mc_n) denotes the representative firm's nominal (real) marginal cost, and n_n is the volume of labor employed in the sector. Firms face price adjustments a la Rotemberg (1982), modified to allow for indexation. Profit maximization results in the following Phillips curve:

$$\pi_n - \pi_{n_{-1}} = \beta\left(\pi_{n_{+1}} - \pi_n\right) + \xi_n \log\left(\frac{p_n^{flex}}{p_n}\right),$$

where p_n^{flex} is a notional flexible (relative) price level

$$p_n^{flex} = \mu mc_n.$$

Finally, equilibrium in the non–traded sector requires

$$c_n = A_n n_n^{\gamma}.$$

3.5 Exporters

Exporters are price takers, with the price of their product set in international markets, and have the same production function as non–traded firms. Profit maximization results in the following export supply curve:

$$P_x y_x = W n_x \longleftrightarrow p_x y_x = w n_x,$$

where:

$$p_x = \frac{P_x}{P} = \frac{P_x^* S}{P} = \frac{P_x^*}{P^*}\frac{SP^*}{P} = p_x^* q,$$
$$y_x = A_x n_x^{\gamma}.$$

3.6 Importers

Monopolistically competitive firms buy foreign goods and sell them in the domestic market, facing demand curves with elasticity ϖ. As with firms in the non–traded sector they also receive a subsidy ι for every unit of imports they acquire, and are also subject to nominal rigidities. Profit maximization leads to the following conditions:

$$p_m^{flex} = \mu m c_m,$$
$$mc_m = q(1-\iota),$$
$$\pi_m - \pi_{m_{-1}} = \beta\left(\pi_{m_{+1}} - \pi_m\right) + \xi_m \log\left(\frac{p_m^{flex}}{p_m}\right).$$

3.7 Labor Market Equilibrium

Equilibrium in the labor market requires that demand for labor in the export and non–traded sectors equal labor supplied by households:

$$n = n_n + n_x$$

3.8 Real GDP

We define real GDP as the weighted sum of non–traded consumption and exports, using steady state relative prices $(\overline{p}_n, \overline{p}_x)$:

$$y = \overline{p}_n c_n + \overline{p}_x y_x$$

3.9 Balance of Payments

Combining the budget constraints of households and firms yields the country's balance of payment:

$$L = L_{-1} e^{(i_{-1}^* + \pi_S)} + \left(SP^* C_m - P_x Y_x\right),$$

where $\pi_S = log(S) - log(S_{-1})$. Deflating by the CPI and steady state output, we obtain a real measure of the balance of payments:

$$l = l_{-1} e^{(i_{-1}^* + \pi_S - \pi)} + \overline{y}^{-1}\left(q c_m - p_x y_x\right),$$

where $l = (L/P)/\overline{y}$ and $p_x = P_x/P$.

3.10 Rest of the World

We define a trade weighted measure of the real terms of trade $tot = p_x^{*\,1-\eta}/p_m^{*\,1-\eta-\overline{tb}}$, where $1-\eta$ denotes the steady–state share of exports in GDP and $\overline{tb}$ denotes the steady state trade surplus, also as a share of GDP. tot follows an autoregressive progress:

$$\log(tot) = \rho_{tot} \log(tot_{-1}) + \varepsilon_{tot}.$$

Finally, foreign interest rates also follow an autoregressive process:

$$i^* = \rho_{i^*} i^*_{-1} + (1 - \rho_{i^*})\overline{i}^* + \varepsilon_{i^*}.$$

4 Steady State, Log–linearization and Calibration

To characterize the steady state and log–linearized version of the model we first specify the functional forms of the premium (Ω_O) and the quadratic loan adjustment cost faced by consumers (Ψ). Ψ is given by $\Psi = \frac{1}{2}\varrho^* \left(\frac{L}{P} - \left(\overline{\frac{L}{P}}\right)\right)^2$, which implies the following form for $\varrho\left(\frac{L}{P}\right)$:

$$\varrho\left(\frac{L}{P}\right) = \varrho^* \left(\frac{L}{P} - \left(\overline{\frac{L}{P}}\right)\right) = \varrho^* \overline{y} \left(\frac{L}{P}\frac{1}{\overline{y}} - \left(\overline{\frac{L}{Py}}\right)\right) = \varrho^* \overline{y}\left(l - \overline{l}\right).$$

l denotes real the real value of loans (in units of consumption) relative to steady state output ($\overline{y}$, to be defined below). Ω_O has the following functional form:

$$log(\Omega_O) = \Omega_O \left(\frac{F}{P} - \left(\overline{\frac{F}{P}}\right)\right) = \Omega_O \overline{y} \left(\frac{F}{P\overline{y}} - \left(\overline{\frac{F}{Py}}\right)\right) = \Omega_O \overline{y}\left(f - \overline{f}\right),$$

with f denoting the real value of FX reserves (in real terms) relative to steady state output.

4.1 Steady State

At steady state $log(\Omega_O) = \Psi = \varrho = 0$. Subsidies are such that $\iota = (\mu - 1)/\mu$. With the exception of real wages, all relative prices and aggregate consumption are set to one:

$$\overline{c} = \overline{p}_m = \overline{p}_n = \overline{q} = \overline{p}^*_x = 1,$$

which implies $c_n = \omega_n$ and $c_m = 1 - \omega_n$. Given the net borrowing condition of the country ($\overline{l} > 0$), exports must be greater than imports at steady state. From the balance of payments we obtain $y_x = 1 - \omega + \overline{l}(\beta^{-1} - 1)(1 - \overline{l}(\beta^{-1} - 1))^{-1} = 1 - \omega_n + \zeta$, which implies $\overline{y} = 1 + \zeta$. It follows that the share of non–traded goods in GDP (η) is given by $\eta = \omega_n/(1 + \zeta)$, while the trade balance ($\overline{tb}$, in percent of GDP) is given by $\overline{tb} = \zeta/(1 + \zeta)$.

Real wages equal the labor share in production $\overline{w} = \gamma$, whereas employment is given by $\overline{n}_n = \omega_n, \overline{n}_x = 1 - \omega_n + \zeta, \overline{n} = 1 + \zeta$. The above steady state is made possible by the following choice of parameters: $\psi = \gamma(1 + \zeta)^{-\phi}$, $A_n = \omega_n^{1-\gamma}$, and $A_x = (1 - \omega_n + \zeta)^{1-\gamma}$.

The inflation target π^T is zero, which implies: $\bar{i} = \bar{j} = \bar{i}^* = \beta^{-1}$. The starting value for S is $S^T = 1$. Depending on the specification of monetary policy, this starting value may constitute a steady state value for S, in the sense that the economy will converge back to S^T. Otherwise, S will drift.

4.2 Calibration

The calibration of the model is presented in the table below. We do not have a specific country in mind; instead our calibration is meant to capture a prototypical small open developing economy. The value of β implies real interest rates in annual terms are 1 percent. The choice of ω_n implies exports constitute about 50 percent of GDP. The value of the labor share γ and the inverse of the labor supply elasticity ϕ are broadly standard, as well as the parameters that describe nominal rigidities (ξ, ξ_m) and market power (μ). With the exception of the degree of exhange rate targeting (which we discuss in the next section), the parameters in the Taylor rule (ρ, α, δ) are also consistent with values in the literature. We discuss the calibration of the intervention rule in the next section.

At steady state, reserves add up to a quarter of annual GDP, or about 6 months of imports which is a simple metric often used to assess reserve adequacy, e.g., at the IMF. Loans by households are also equal to 25 percent of GDP, which is at the lower end of the ratio of credit to GDP found in developing countries. The value of Ω_O (0.1) implies an increase in reserve holdings of 1 percent of GDP lowers the risk premium by 10 basis points. We also explore the implications of a much lower values of Ω_0 (0.01). Finally, the value of ϱ^* is very small: an increase in loans of one percent of GDP drives a wedge between lending rates and the houeshold's discount factor of 1 basis point. As already mentioned, this parameter only serves to ensure that consumption (and loans in real terms) eventually returns to its steady state value.

Parameter	Value	Parameter	Value
ϕ	0.5	ξ, ξ_m	0.1,0.5
β	0.9975	ρ_{i^*}	0.8
ϱ^*	0.01	ρ_{tot} (temporary)	0.8
ω_n	0.5	ρ_{tot} (permanent)	0.9999
α	1.5	μ	1.2
δ	0	γ	0.7
ρ	0.7	ρ_f	0.7
Ω_O	0.1	π^T	0
$\bar{l}$	1	$\bar{f}$	1
$\overline{tb} \approx \zeta$	0.0025	η	0.4987

4.3 The Log–linearized Model

The log–linearized version of the model is summarized in Box 1. All variables are presented in log–deviations from steady state, except for loans and reserves in real terms, which are presented as level deviations in percent of steady state output ($\hat{x} = \frac{(x-\overline{x})}{\overline{y}}$, for $x = L/P$, F/P), and interest rates which are presented as level deviations ($\hat{z} = z - \overline{z}$, for $z = i = i^* = j$).

Box 1. The log–linearized model

The balance of payments, in real terms, relative to steady state output:
$\hat{l} = \beta^{-1}\hat{l}_{-1} + \bar{l}\beta^{-1}(\hat{i}^*_{-1} + \hat{q} - \hat{q}_{-1}) + (1-\eta-tb)(\hat{q}+\hat{c}_m) - (1-\eta)(\hat{p}_x + \hat{y}_x)$

Demand for imports: $\hat{c}_m = -\hat{p}_m + \hat{c}$

Demand for non–traded goods: $\hat{c}_n = \frac{(1-\omega_n)}{\omega_n}\hat{p}_m + \hat{c}$

Euler equation: $\hat{c} = \hat{c}_{+1} - (\hat{j} - \hat{\pi}_{+1}) - (1+\zeta)\varrho\hat{l}$

Labor supply: $\phi\gamma^{-1}\hat{y} = \hat{w} - \hat{c}$

Phillips curve for non–traded goods: $\hat{\pi}_n = \frac{1}{1+\beta}\hat{\pi}_{n-1} + \frac{\beta}{1+\beta}\hat{\pi}_{n+1} + \frac{\xi}{1+\beta}(\hat{w} + \frac{1-\gamma}{\gamma}\hat{c}_n + \frac{1-\omega_n}{\omega_n}\hat{p}_m)$

Phillips curve for imports: $\hat{\pi}_m = \frac{1}{1+\beta}\hat{\pi}_{m-1} + \frac{\beta}{1+\beta}\hat{\pi}_{m+1} + \frac{\xi_m}{1+\beta}(\hat{q} - \hat{p}_m)$

Inflation: $\hat{\pi} = \omega_n\hat{\pi}_m + (1-\omega_n)\hat{\pi}_n$

Export supply curve: $\hat{y}_x = \frac{\gamma}{1-\gamma}(\hat{w} - \hat{p}_x)$

Relative price of imports: $\Delta\hat{p}_m = \hat{\pi}_m - \hat{\pi}$

Aggregate output: $\hat{y} = \eta\hat{c}_n + (1-\eta)\hat{y}_x$

Uncovered interest parity with FX interventions: $\hat{i} = \hat{i}^* + \hat{q}_{+1} - \hat{q} + \hat{\pi}_{+1} + \Omega_O(1+\zeta)\hat{f}$

Lending rates: $\hat{j} = \hat{i}$

Interest rate rule: $\hat{i} = \rho\hat{i}_{t-1} + (1-\rho)(\alpha\hat{\pi} + \delta\hat{y} + \chi\hat{S})$

Intervention rule: $\hat{f} = \rho_f\hat{f}_{-1} - (1-\rho_f)(\omega\hat{S} + \vartheta(\hat{S} - \hat{S}_{-1}))$

The real exchange rate: $\hat{q} = \hat{q}_{-1} + \hat{S} - \hat{S}_{-1} - \hat{\pi}$

The relative price of exports: $\hat{p}_x = (1-\eta)^{-1}\hat{tot} + \hat{q}$

Terms of trade: $\hat{tot} = \rho_{tot}\hat{tot}_{-1} + \epsilon_{tot}$

Foreign interest rates: $\hat{i}^* = \rho_{i^*}\hat{i}^*_{-1} + \epsilon_{i^*}$

5 Simulations

5.1 A Shock to Foreign Interest Rates

We now simulate the model when it is hit with a foreign interest rate shock ($e_{i^*} = 1$, i.e., a one hundred basis point increase in foreign rates). We compare the model's response under four monetary policy settings: (i) Pure inflation targeting (IT)/flexible exchange rate regime, in which the authorities care solely about inflation and do not target the exchange rate nor intervene in the FX market; (ii) fixed exchange rate regime via interest rates; (iii) fixed exchange rate regime via interventions; and (iv) managed float, in which the authorities lean against the wind but do not target a specific exchange rate level. The pure IT case will serve as a benchmark. For all four regimes, the exchange rate objective in the interest rate rule (Υ) is set as in Eq. (2) with $\eta = 0$. The implications of each regime for the parametrization of the Taylor rule (1) and the intervention rule (3) are as follows:

Regime/parameter	χ	ω	ϑ
IT pure float	0	0	0
Fixed via interest rate	Inf	0	0
Fixed via interventions	0	Inf	0
Managed float	0	0	6

The choice of regimes merits three remarks. First, we pay special attention to the two alternative ways of fixing the nominal exchange rate (interest rates and intervention) to help understand the mechanisms involved. It must be stressed that these are somewhat extreme cases; in practice, central banks that peg the exchange rate typically use a combination of interventions and interest rate policy. Second, in the case of the intervention–based peg and the managed float, the authorities continue to use interest rates to target inflation, i.e., they are relying on two policy instruments instead of one. Third, in the case of the managed float, there is some persistence in reserve accumulation (as ρ_f is set to 0.7).

Figure 1 presents the results. The IT case shows the basic challenges such a shock presents to the authorities: a rise in foreign rates pushes the domestic currency to depreciate, inducing inflation through import prices, but at the same time supporting the export sector. Under "pure" IT, monetary policy will respond by raising nominal rates, somewhat offsetting the impact of the shock on the exchange rate and putting downward pressures on domestic consumption. The trade balance improves, as exports increase and imports decline following the real exchange rate depreciation and the tightening of policy. Despite the increase in the trade balance, the country's net foreign liabilities worsen (not shown) because of the higher interest rate burden.

Under IT, the nominal exchange does not return to its initial level. The rising price level resulting from this shock leads the currency to settle at a more depreciated level. The same is true for the managed float specification, as the central intervenes to smooth the pace of adjustment but does not target the exchange rate level. By contrast, under both types of pegs the exchange rate returns to the original level.

Fixing the exchange rate via interest rates leads to a decline in inflation, at the cost of a sharper economic decline than in the pure IT case. The reason is that domestic interest rates must match the foreign interest rate increase. The large policy tightening contracts consumption and results in the large decline in inflation. The trade balance improves by more than under IT on account of the much larger policy–induced squeeze in imports. This greater impact of the external shock on the real economy is a well known weakness of fixed exchange rate regimes, going back to Friedman (1953).

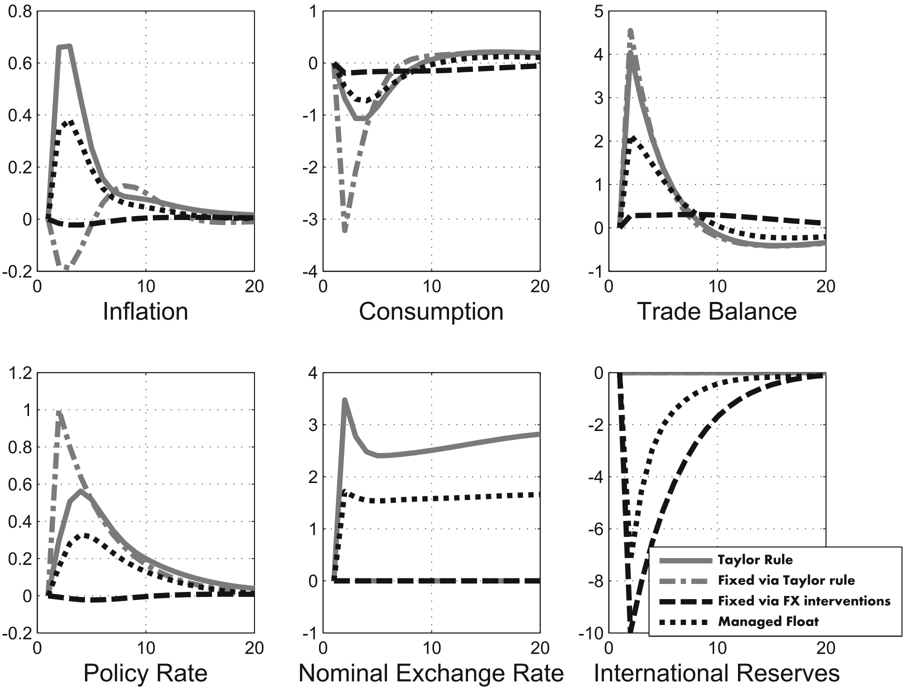

Fig. 1 Foreign Interest Rate Shock under Different Exchange Rate Regimes "Pure" IT (*grey, solid line*), fixed via interest rate rule (*grey, dashed with dots*), fixed via interventions (*black, dashed*), IT managed float (*black, dotted*). Units are percentage deviations from steady state

The macroeconomic impact of the shock looks considerably different when the authorities fix the exchange rate through interventions. The offsetting effect on the UIP premium allows the nominal exchange rate to stay constant, while also insulating domestic interest rates. The economy contracts slightly: the temporary increase in foreign interest rates increases the debt repayment burden for households, as they are net foreign debtors, which slightly raises the effective interest rates faced by households (in the Euler equation). Inflation and policy rates decrease somewhat as a result. Despite these effects, the impact of the shock is almost zero. Note that, since the real exchange rate barely depreciates (not shown), there is little boost to exports (and hence output). The insulation of the economy comes at the cost of a large sale of reserves (10 percent of its stock in real terms, which given the calibration is also equal to 10 percent of the economy's quarterly GDP at steady state).

The managed float show the advantages of active exchange rate management. Interventions allow interest rates to stay lower than in the pure float or the interest–rate peg, thus reducing the impact on consumption. The managed float also allows for some exchange rate depreciation (at least temporarily), thus providing a short–term impulse to the export sector that is otherwise not available under fixed regimes. The decline in the stock of reserves is smaller and less persistent than under the intervention–based peg.

The simulations illustrate the costs of implementing a fixed exchange rate regime with interest rate policy alone. In the float case the rates increase *in order* to fight inflation pressures, while under the interest rate–based peg the rates increase *despite* a fall in inflation and in economic activity. Interventions, by contrast, give the policy rates room for maneuvering in response to the (small) contraction of the economy. As a result, the economic impact is much smaller.

It is worth re–emphasizing that the channel through which interventions work is different from the traditional channel of monetary policy, which relies on nominal rigidities. This can be seen by simulating a version of the model in which nominal rigidities (in both the non–traded and import sector) are turned off, shown in Fig. 2. The economy's response to the foreign interest rate shock is now identical under pure IT and under an interest–rate based peg, as the choice of nominal anchor has no real effects. Under both regimes, consumption declines as domestic real interest rates increase, and combined with the resulting real appreciation it leads to an improvement in the trade balance. Unlike these regimes, intervention policy does have real effects, as it influences interest rate premia and real decisions, and the choice of intervention policy matters. Moreover, the effects are broadly similar to the version of the model with nominal rigidities, which highlights the robustness of intervention policy to this particular mechanism.

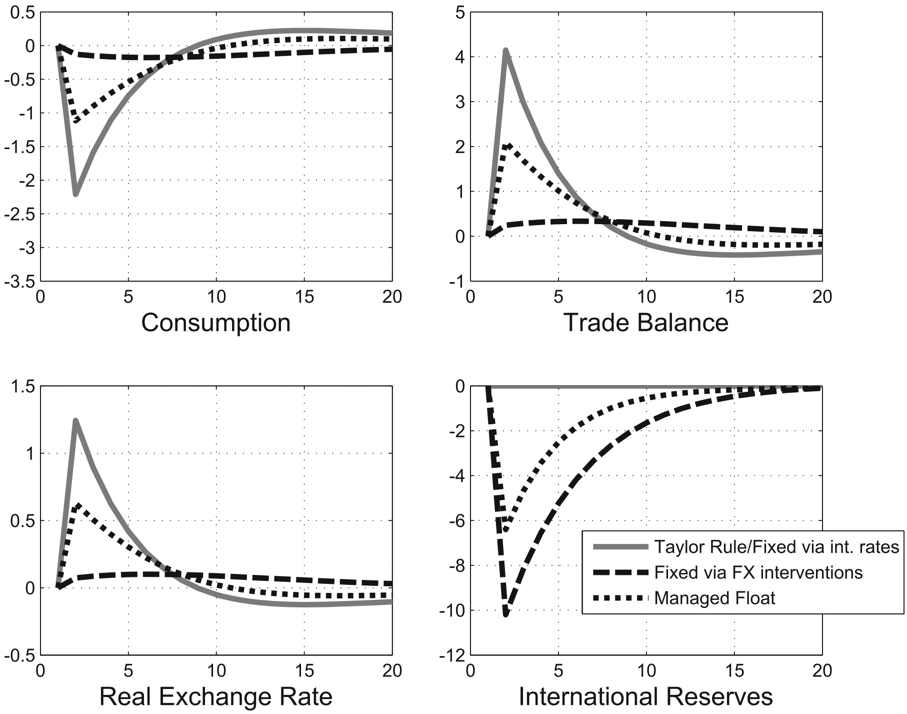

Fig. 2 Foreign Interest Rate Shock under Different Exchange Rate Regimes, Flexible Prices "Pure" IT and fixed via interest rates (*grey, solid line*), fixed via interventions (*black, dashed*), IT managed float (*black, dotted*). Units are percentage deviations from steady state

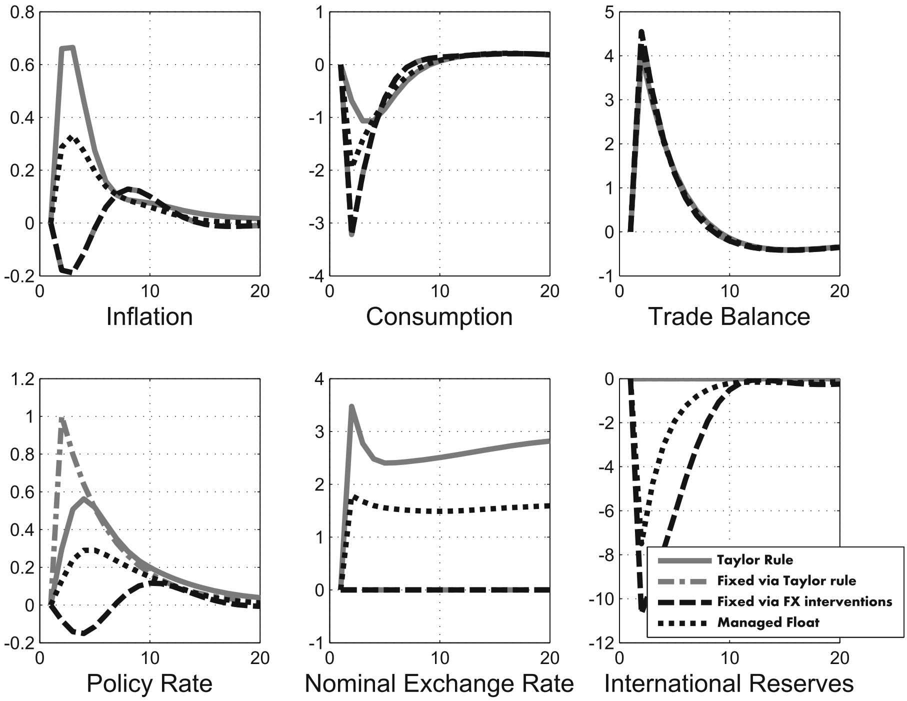

Fig. 3 Foreign Interest Rate Shock under Different Exchange Rate Regimes, Alternative Specification "Pure" IT (*grey, solid line*), fixed via interest rate rule (*grey, dashed with dots*), fixed via interventions (*black, dashed*), IT managed float (*black, dotted*). Units are percentage deviations from steady state

The effect of interventions does depend on whether interventions affect premia on all domestic assets (central bank paper and loans) or only on the domestic asset whose gross supply is changing (central bank paper). To understand the importance of this assumption, we reintroduce nominal rigidities but replace the perfect substitutability between loans and central bank paper ($j = i$) with an alternative specification in which loans and foreign borrowing are perfect substitutes up to a constant premium ($j = i^* + \Delta\hat{S}_{+1} + log(\Omega_L)$), which implies ($j = i - log(\Omega_O(F/P)) + log(\Omega_L)$).[11] In this case, shown in Fig. 3, the intervention–based peg delivers exactly the same result on consumption and other real variables as the interest–rate based peg. By selling reserves to maintain the peg, the central bank is increasing the premia on loans relative to central bank paper. Since the increase in the premia is proportional to the increase in foreign interest rates, lending rates (the only rates that matter for private sector decisions) increase by the same amount than foreign interest rates.

[11] We set $log(\Omega_L)$ to zero for the sake of simplicity.

5.2 A Shock to the Terms of Trade

We now briefly discuss simulations of the model to a negative terms of trade shock ($e_{tot} = -1$, i.e., a worsening of one percent), under the four policy regimes described above. We distinguish between a shock with temporary effects, in which the autoregressive coefficient for the terms–of–trade process (ρ_{tot}) is set to 0.8, and a shock with quasi–permanent effects ($\rho_{tot} = 0.999$). These simulations are shown in Figs. 4 and 5, respectively.

Under IT a negative but temporary terms of trade shock triggers an immediate nominal and real depreciation, which helps offset the impact of the shock on exports. Output falls nonetheless. The shock lowers consumption because of the income effect, as overall demand for labor and hence wages decrease. The decline in consumption and the reallocation of labor from the exports sector to the non–traded sector generates a decline in inflation (despite the depreciation) which results in a decrease in the policy rate. Under a quasi–permanent shock, income effects are amplified, which reduces consumption further but also increases labor supply and helps support output. Nominal exchange rate flexibility allows for a rapid (larger) real

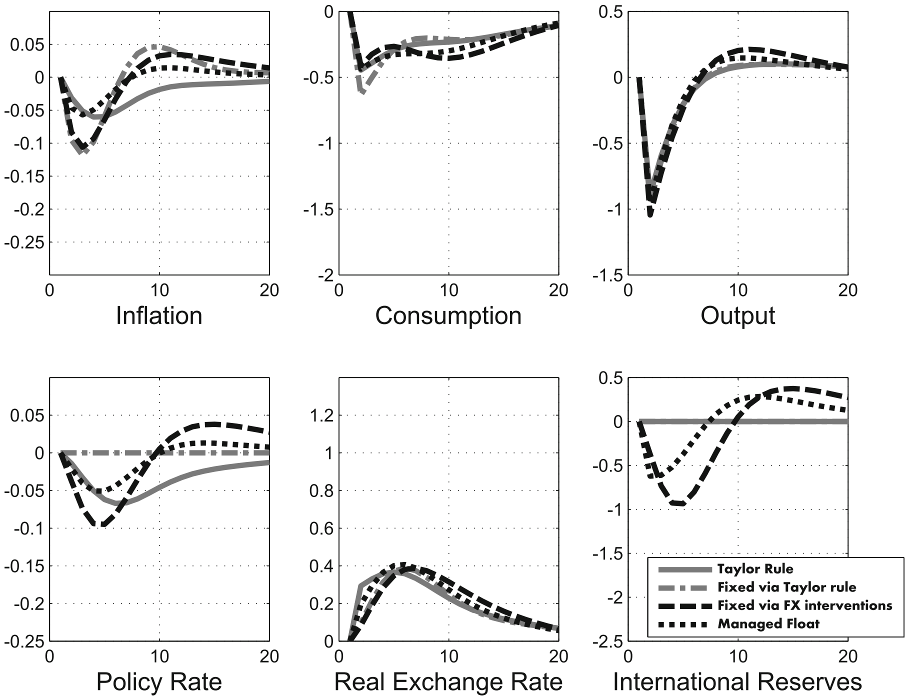

Fig. 4 Temporary terms-of-trade shock under different exchange rate regimes "Pure" IT (*grey, solid line*), fixed via interest rate rule (*grey, dashed with dots*), fixed via interventions (*black, dashed*), IT managed float (*black, dotted*). Units are percentage deviations from steady state

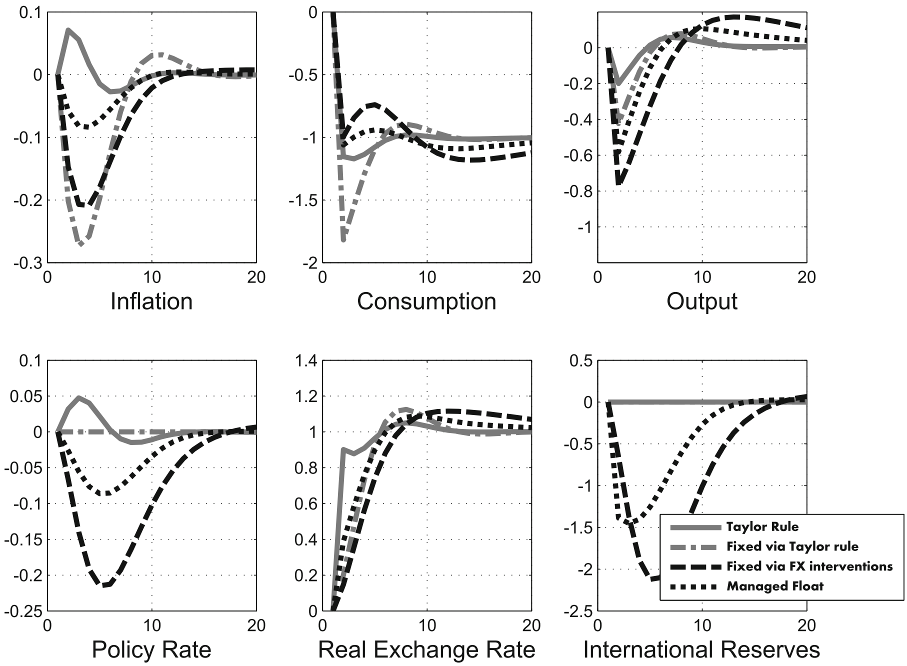

Fig. 5 Quasi–permanent terms-of-trade shock in different exchange rate regimes "Pure" IT (*grey, solid line*), fixed via interest rate rule (*grey, dashed with dots*), fixed via interventions (*black, dashed*), IT managed float (*black, dotted*). Units are percentage deviations from steady state

appreciation, which helps offset the impact of the shock on exports but now results in an increase in inflation (and policy rates).

Against this background, policies that target the nominal exchange rate reduce the immediate real depreciation and therefore amplify the effect of the shock on output, as the real depreciation must be achieved through a decrease in inflation. This is most visible when the shock is quasi–permanent. Intervention–based pegs delay the real appreciation the longest and hence have the largest decline in output. The reason for the longer delay is that interventions allow policy makers to lower interest rates aggressively in response to the shock, which diminishes the decrease in inflation.

These simulations highlight the risk that intervention policies may amplify the effect of external shocks by limiting the exchange rate channel to play itself out.

5.3 Welfare Analysis

In this section we briefly summarize the macroeconomic volatility implied by the various rules in response to the two shocks we focus on. We also assess the various rules in response to the two shocks we focus on. To do so, we use:

(i) the loss function implied by the preferences of the representative agent, and
(ii) two ad–hoc loss functions.

As shown in the appendix, a second order approximation of the discounted sum of the representative agent's utility (denoted U) around its steady state value, using the model equations, results in the following relation:

$$U - \overline{U} \approx -\frac{1+\phi}{\gamma} \sum_{t=0}^{\infty} \beta^t E_0 \left[\hat{y}_t^2 \right] + t.i.p.,$$

where $t.i.p.$ stands for terms independent of policy. Up to a second–order approximation utility depends solely on the volatility of output, because of the implications of output volatility for employment volatility. It does not depend on consumption volatility because of our assumption of log utility. In addition, since we assume that price setting is symmetric across firms in each sector (non–traded and import sector), inflation volatility does not affect utility.

We also rely on two ad–hoc loss functions to complement the analysis. In the first one, $L_1 = -\sum_{t=0}^{\infty} \beta^t E_0 \left[\hat{c}_t^2 \right]$, so that consumption volatility is the sole objective of monetary policy. In the other function, $L_2 = -\sum_{t=0}^{\infty} \beta^t E_0 \left[\hat{\pi}_t^2 + \hat{y}_t^2 \right]$, which implies the central bank cares equally about inflation and output volatility.

These results are summarized in the table below. Results are displayed in absolute value, so that the lower the number the smaller the welfare cost. For purposes of comparison, the welfare measures have been normalized with respect to the pure IT regime.

	IT pure float	Fixed via Taylor	Fixed via interventions	IT managed float
Foreign Interest Rate Shock				
U	1	0.55	0.03	0.36
L_1	1	3.93	0.08	0.48
L_2	1	0.50	0.02	0.36
Temporary ToT Shock				
U	1	1.13	1.53	1.13
L_1	1	1.22	1.30	1.20
L_2	1	1.15	1.54	1.12
Quasi–permanent ToT Shock				
U	1	4.26	24.08	9.61
L_1	1	1.02	1.01	1.00
L_2	1	6.74	23.12	8.69

In the case of shocks to foreign interest rates, intervention–based pegs unambiguously dominate other regimes. This is not surprising; as Fig. 1 indicates, this regime helps stabilize output, consumption and inflation almost perfectly. In the case of terms of trade shocks, exchange rate flexibility/pure IT helps deliver smaller welfare costs, especially if welfare is evaluated in terms of output volatility (U) or output and inflation ($L2$), but there is little difference across regimes if welfare is evaluated in terms of consumption volatility (L_1). The more persistent the terms of trade shock the larger the dominance of IT relative to the other regimes. In the case of a quasi–permanent shock, the intervention–based peg performs very poorly in terms of output and inflation volatility, but about the same as IT in terms of consumption volatility.

Our results suggest that interventions are best deployed in response to some shocks rather than others. We leave a formal investigation of the optimal intervention rule for further work.

5.4 Limits of Interventions

The previous section has shown that there can be advantages to using sterilized interventions as part of the monetary policy toolbox, especially as a way of insulating the economy against certain types of external shocks. The previous section has also shown that interventions can be counterproductive however, from a welfare perspective, if they hamper exchange rate adjustment. Beyond the desirability of interventions, here we briefly discuss two broad sets of arguments that limit what can be achieved with intervention policy.

The first set of arguments is that, in practice, intervention policies are often abandoned if they lead to persistent reserve losses and countries run out of reserves. The opposite may also be true, i.e., that policies that result in persistent reserve accumulation may force the central bank to stop, e.g., out of concern with the quasi fiscal implications (especially if there is a gap between the interest rate on reserves and the interest rate on government securities). Market perception that reserves policies may be reversed can often lead to speculative attacks, as is well known from the literature on balance of payment crises.[12] More generally, most intervening central banks prefer to keep their intervention tactics (i.e. the reaction function) hidden, if possible, to avoid facing such runs. This lack of transparency limits what can be achieved with these policies, since part of the effects of interventions we observed in our simulations stem from the predictability of the intervention rule. Such concerns are less acute for the interest rate rule, because the central bank is the ultimate market maker in the money market and because capital gains and losses are very limited for short-duration securities—unlike in the FX market.

While our analysis assumes the central bank always knows perfectly what kind of shock it deals with, in reality this perfect knowledge is difficult to achieve and markets often have a different opinion, leading them to probe the central bank's resolve. Our simulation of the terms of trade shock showed how a quasi–persistent shock to the terms of trade leads to much larger reserves losses than a temporary shock. If the central bank only intervenes to offset the effects of temporary shocks but markets believe it is mistaken in its assessment of the shock and will have to abandon its interventions in the near term, the threat of an attack increases.

The second set of arguments on why interventions may not be viable as a systematic policy instrument involves the so called "impossible trinity'.[13] This asserts that

[12]See Krugman (1979).

[13]The literature on the impossible trinity is time-honored and extensively large. See Obstfeld, Shambaugh and Taylor (2004) for a historical perspective.

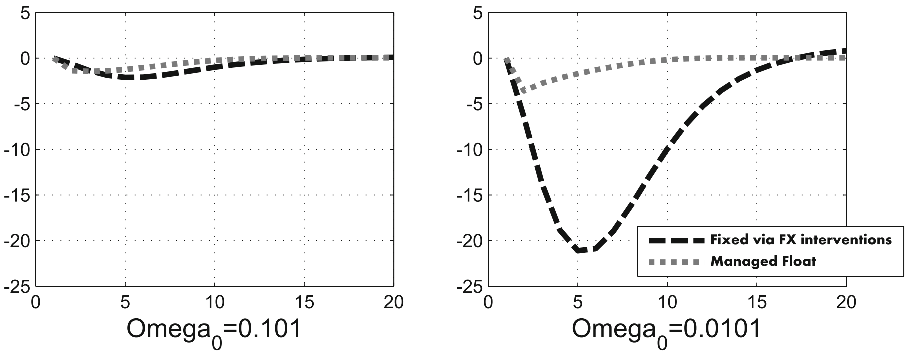

Fig. 6 Quasi–permanent terms–of–trade shock, intervention–based exchange rate regimes. Strong sensitivity to interventions (*left quadrant*), weak sensitivity to interventions (*right quadrant*)

independent monetary policy cannot function with a fixed exchange rate and a free capital account, because the financial flows unleashed by any interest rate differential would make the peg short-lived. For instance, an attempt to keep interest rates lower (say, to stimulate the economy) than foreign rates adjusted for a risk premium would trigger an outflow, eventually bringing down the peg, as FX reserves run out.

Our analysis allows for the possibility that domestic and foreign assets are not perfect substitutes, even if the capital account is fully open, therefore allowing for a combination of exchange rate management and monetary policy autonomy. Although in principle this would seem to violate the impossible trinity, the additional degree of freedom ultimately depends on the sensitivity of risk premia to the intervention. To show the importance of this parameter, we look at reserve losses when the economy is hit with a shock to the terms of trade, under both an intervention–based peg and a managed float (Fig. 6). In the left quadrant, we show reserve losses under the benchmark calibration ($\Omega_O = 0.101$); in the right quadrant we show the results when the elasticity of the premium is ten times smaller ($\Omega_O = 0.0101$). When the elasticity is much smaller, a one percent shock to the terms of trade results in a 20% loss of reserves under the intervention–based peg, as opposed to 2 percent when the elasticity is higher. This simulation underscores the risks to pegging via interventions when interest premia are not very sensitive to balance sheet operations, as predicted by the impossible trinity.

An important corollary is that managed floating regimes can be more robust to uncertainty about the effectiveness of interventions. Because the rule is specified in terms of volumes of intervention, a low sensitivity of the premium to interventions implies that the intervention will not make much difference, but there is also little risk of running out of reserves.

6 Conclusions

The modeling of regimes that combine IT with various degrees of exchange rate management—and of the mechanisms that make such combinations possible—is an important issue for many central banks and institutions. Unlike for "pure" IT, an analytical framework for these hybrid regimes has not yet been established, and standard analytical approaches appear unfit for the state of affairs in emerging and developing countries.

In general, the coexistence of IT with some kind of exchange rate management is a common phenomenon in many countries, at least informally. For instance, there are countries with a fixed or strongly managed exchange rate that are in transition towards a more flexible exchange rate regime and implement elements of inflation targeting by controlling short-term interest rates. Others attempt to control excessive exchange rate fluctuations by interventions of various forms (e.g., sterilization of inflows). Some even recognize two explicit intermediate targets in terms of the exchange rate and inflation bands.

By explicitly introducing balance sheet effects in a new-Keynesian model with a simple banking sector, we have provided a framework for studying the effects of intervention policies as part of a broader monetary policy toolbox. Given the experience of many central banks, our focus has been on hybrid frameworks that use interventions to manage the exchange rate, while also maintaining control of short term interest rates to keep inflation anchored. We have shown that intervention policies can help insulate the economy against certain types of shocks, though we have also shown that, in some cases, limiting exchange rate adjustment can also be counterproductive from a welfare perspective. This nuance raises the stakes for intervention policy, in that policy mistakes can be costly.

Two extensions of this work appear important for future research. First, more work can be done in mapping the intervention mechanism to micro-foundations, as well as the explicit modeling of the limits of interventions and the possibility of runs. Second, the framework presented here could be extended to analyze other aspect of monetary/financial policy that have received considerable attention since the global financial crisis, such as macro prudential policies and the need for coordination with intervention policy.

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Appendix

Second–order approximation to utility

Starting from the steady state (at period -1), taking a second order approximation to the discounted sum of utility flows yields the following relation:

$$U = E_0\left[\sum_{t=0}^{\infty}\beta^t U_t\right] \approx \overline{U} + \sum_{t=0}^{\infty}\beta^t E_0\left[\underbrace{\hat{c}_t - (1+\zeta)\hat{y}_t}_{A_t}\right] - \frac{1+\phi}{\gamma}\sum_{t=0}^{\infty}\beta^t E_0\left[\hat{y}_t^2\right].$$

Note that $\hat{c}_t - (1+\zeta)\hat{y}_t = (1-\omega_n)\hat{c}_{m,t} - (1-\omega_n+\zeta)\hat{y}_{x,t}$. Forward iterations of the balance of payments imply:

$$\sum_{t=0}^{\infty} \beta^t E_0 [A_t] = (1+\zeta) \sum_{t=0}^{\infty} \beta^t E_0 \left[t\hat{o}t_t - \bar{l}\beta \hat{i}_t^* \right] = t.i.p.,$$

where $t.i.p.$ denotes terms independent of policy. The above relation implies the discounted sum of utility, up to a second–order approximation, is proportional to the discounted sum of squared variations in output:

$$U - \overline{U} \approx -\frac{1+\phi}{\gamma} \sum_{t=0}^{\infty} \beta^t E_0 \left[\hat{y}_t^2 \right] + t.i.p.$$

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