Does information matter? (for how interest rates and exchange rates comove)*

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Abstract

This paper compares the link between exchange rates and interest rates under full information and two alternative asymmetric information approaches. In doing so, it also distinguishes between cases of expansionary and contractionary depreciations. Full information results do not appear to be robust to the presence of informational frictions. For economies exhibiting expansionary or strongly contractionary depreciations, such frictions are responsible for two optimal deviations from full information outcomes: i) under asymmetric information with signal extraction, the realisation of a relatively less frequent shock leads the central bank to behave as if a more likely disturbance had instead taken place; and ii) under asymmetric information without signal extraction, the monetary authorities does not react on impact to shocks hitting the economy. Finally, in the case of mildly contractionary depreciations, both asymmetric information models predict a lack of response of the central bank to aggregate demand shocks, as opposed to an offsetting movement in interest rates under full information.

Keywords: Transmission mechanism; Emerging market economies; Exchange rate; Monetary policy; Imperfect information

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Non-technical summary

The link between interest rates and exchange rates has attracted considerable research attention over recent years. This is understandable given that interest rates and exchange rates play an important role in influencing macroeconomic developments. First, they affect key variables such as inflation, output and flows of international trade. Second, given that inflation and output relate to policymaker's goals, they directly (in the case of interest rates) and indirectly (in that of exchange rates) contribute to the determination of economic policy. Third, interest rates and exchange rates constitute crucial financial variables reflecting the state of domestic and international capital markets, respectively.

Most of the studies focusing on the link between interest rates and exchange rates have been conducted under the assumption that agents have full information about the state of the economy. Under standard assumptions, standard models show that adverse real and financial shocks lead to a weakening in the exchange rate and a rise in interest rates. Balance sheet effects could lead to a reduction in the positive impact on economic activity arising from a weakening in the exchange rate. In this case, previous studies find that there is less of a case for raising interest rates in the face of adverse risk premium shocks. As a result, the exchange rate ends up depreciating by a larger amount. In the face of an adverse real shock, the exchange rate will also depreciate by more (and interest rates be further lowered), the smaller the responsiveness of output to exchange rates. Finally, the literature has investigated situations under which a weakening in domestic currencies could lead to contractions in economic activity (that is, "contractionary devaluation" scenarios). The covariance between exchange rates and interest rates, conditional on adverse risk premium and net export shocks, can be shown to be turn positive for strongly, and under forward-looking foreign exchange markets, also mildly contractionary depreciations.

It might surprise many readers that the literature has focused on full information models as it is a fact of life that agents do not have access to real-time information about all relevant economic data, while in addition some agents are better informed about the evolution of the economy than others. In particular, policymakers do not afford the luxury of an error-free assessment of current market conditions at the time of taking their decisions. Building on this insight, the purpose of this paper is to extend the existing studies by assessing the role that informational frictions play in determining comovements between interest rates and exchange rates. I derive results under the assumption of both full and imperfect information. Regarding the latter case, I study two types of asymmetric information: a) asymmetric information with signal extraction, in which case the central bank learns about real-time data properties embodied in the latest exchange rate developments; and b) asymmetric information without signal extraction, shocks are not known to any agents in the economy at the time of the monetary policy decision.

The results of this paper show that full information outcomes appear not to be robust to the presence of informational frictions. More concretely, three important differences arise between full information and the imperfect information models analysed here. For economies exhibiting expansionary or strongly contractionary depreciations, such frictions are responsible for two optimal deviations from full information outcomes: i) under asymmetric information with signal extraction, the realisation of a relatively less frequent shock leads the central bank to behave as if a more likely disturbance had instead taken place; and ii) under asymmetric information without signal extraction, the monetary authorities does not react on impact to shocks hitting the economy. Finally, in the case of mildly contractionary depreciations, both asymmetric information models predict a lack of response of the central bank to aggregate demand shocks, as opposed to an offsetting movement in interest rates under full information.

1 Introduction

The relation between interest rates and exchange rates has attracted considerable research attention over recent years. This is understandable given that interest rates and exchange rates play an important role in influencing macroeconomic developments. First, they affect key variables such as inflation, output and flows of international trade. Second, given that inflation and output relate to policymaker's goals, they directly (in the case of interest rates) and indirectly (in that of exchange rates) contribute to the determination of economic policy. Third, interest rates and exchange rates constitute crucial financial variables reflecting the state of domestic and international capital markets. The research interest has been equally intense in industrial and developing countries. One factor fostering the development of such analyses has been the increasing role played by price-stability oriented monetary frameworks - including inflation targeting - around the globe. In the case of emerging market economies (EMEs), many have recently introduced changes in their monetary and exchange rate policies, moving to inflation targeting regimes which operate officially under flexible exchange rate regimes.[1] Among these countries, exchange rate variability - in itself and *vis-à-vis* interest rate variability- has in recent years risen compared to previous periods characterised by far more rigid exchange rate regimes, even if the extent of such fluctuations is still a matter of debate.

Most of the studies focusing on the link between interest rates and exchange rates have been conducted under the assumption that agents have full information about the state of the economy. Under standard assumptions, standard models show that adverse real and financial shocks lead to a weakening in the exchange rate and a rise in interest rates. Those standard assumptions include that an exchange rate weakening has a positive impact on economic activity. One area that has recently been investigated concerns how

[1] See, *e.g.*, Amato and Gerlach (2002), Carare and Stone (2003) and Fraga et al. (2003).

the model results are affected by variations in the responsiveness of aggregate demand to the exchange rate. Detken and Gaspar (2003) and Eichengreen (2005) assess the situation of adverse balance sheet effects as eliciting a lower response of aggregate demand to exchange rates. In this case, they find that there is less of a case for raising interest rates in the face of adverse risk premium shocks. As a result, the exchange rate ends up depreciating by a larger amount. Eichengreen (2005) also finds that, in the face of an adverse real shock, the exchange rate will also depreciate by more (and in this case interest rates be further lowered), the smaller the responsiveness of output to exchange rates. Another set of results is reported by Eichengreen (2005) and Sánchez (2005), who explicitly analyse situations under which a weakening in domestic currencies could lead to contractions in economic activity (that is, "contractionary devaluation" scenarios).[2] The former author shows that the covariance between exchange rates and interest rates, conditional on adverse risk premium and net export shocks, is negative for expansionary depreciations and positive for strongly contractionary ones. Sánchez (2005) confirms these findings, but deviates from Eichengreen (2005) in reporting that the positive comovements between exchange rates and interest rates also obtain under mildly contractionary depreciations. The latter result arises from the introduction of forward-looking behaviour in the foreign exchange market, which also raises the issue of whether non-fundamental factors play a role in determining the solution to the model in the case of mildly contractionary depreciations.[3]

[2] They do so by allowing for an overall negative effect of weaker real exchange rates on output in the aggregate demand schedule. One reason behind this non-standard effect, namely the presence of balance sheet effects arising from liability dollarisation, has attracted most attention in the recent literature (Chang and Velasco, 2001; Céspedes et al., 2003 and 2004; and Morón and Winkelried, 2005). However, it is worth mentioning that there is a large number of rationales for contractionary devaluations and depreciations: Caves et al. (2002) report ten such effects in their celebrated textbook!

[3] It is worth mentioning that, although all studies discussed in this paragraph have in common the use of full information frameworks, they also present some modeling specificities. For instance, Detken and Gaspar's (2003) model displays forward-looking features concerning goods and financial markets, while Eichengreen's (2005) is basically a backward-looking model. Sánchez's (2005) model is somewhere in between, sharing with Detken and Gaspar (2003) the forward-looking features concerning financial markets, while displaying

One conceptual point in common between all the studies discussed in the previous paragraph is the interpretation of their results as involving optimal monetary policy. More concretely, exchange rate smoothing by means of interest rates is thus shown to originate in optimal policy under flotation. The emphasis on optimal policy distinguishes this literature, at least from a terminological point of view, from other analyses commonly describing similar comovements between interest rates and exchange rates as "fear of floating" - as also discussed in Edwards (2002).[4]

The distinction between expansionary and contractionary depreciations is necessary if one wishes to address the relation between interest rates and exchange rates in a general fashion, that is, for the cases of both advanced and developing countries. Authors such as Calvo (2001), Calvo and Reinhart (2001 and 2002) and Eichengreen (2005) have insisted that there are a number of important differences between advanced economies and EMEs. The latter are seen as being prone to exhibiting liability dollarisation, credibility problems, a high degree of exchange rate pass-through and non-stationarities in the inflationary process. The literature normally finds that these specificities of EMEs are responsible for a relatively small degree of exchange rate flexibility in these economies - what Calvo and Reinhart (2002) label "fear of floating".[5] In particular, liability dollarisation is believed to allow exchange rate depreciations to give rise to contractionary balance sheet effects by raising the domestic-

like Eichengreen (2005) backward-lookingness in the goods market.

[4]Economic models permit us to go beyond reduced-form characterisations of interest rates and exchange rates in terms of comovements. Pending deeper structural empirical analyses, Sánchez (2005) analyses some case studies among EMEs that do not provide us with an entirely clear picture. It appears however to be the case that, in response to adverse risk premium shocks, the exchange rate has tended to depreciate on impact, thereafter strengthening alongside interest rate hikes. The situation is less clear-cut when it comes to shocks characterised by an exogenous fall in net exports, which have, in the cases analysed by the author, taken place at the same time as adverse shocks to risk premia.

[5]This means that, despite the recently proclaimed switch to floating exchange rates, the evidence seems to suggest a reversion to some degree of exchange rate management, albeit one which seems to be less tight than before the crisis. In this regard, some analysts have found considerable discrepancies between the *de jure* exchange rate classifications and *de facto* regimes (see *e.g.* Reinhart and Rogoff, 2004).

currency real value of external liabilities. That the sources of contractionary devaluations may be broader than this is highlighted by the fact that the empirical literature has generally found that weaker currencies tend to induce contractions in EMEs, even after including a number of different controls (see Ahmed, 2003, and the references cited therein). In this context, the work of Eichengreen (2005) and Sánchez (2005) is an attempt to rationalise the lack of exchange rate flexibility by looking at interest rate reactions aimed at offsetting variability in foreign exchange markets.

The focus on full information models that exists in the theoretical literature might surprise many readers as it is a fact of life that agents do not have access to real-time information about all relevant economic data, and that some agents are better informed about the evolution of the economy than others. In particular, policymakers do not afford the luxury of an error-free assessment of current market conditions at the time of taking their decisions. Building on this insight, the present paper addresses the link between interest rates and exchange rates for cases when there are informational imperfections. In doing so, I start by setting up a simple full information model, which draws from the way the recent literature has formulated small open economy frameworks under flexible exchange rates.[6] As in the latter paper, I use backward-looking inflationary expectations and forward-looking financial markets. Following Sánchez (2005), I distinguish between cases when depreciations are expansionary and contractionary, while also incorporating the role of exchange rate pass-through into domestic prices. I extend the basic full information framework by deriving results also under the assumption of imperfect information. More concretely, I study two types of asymmetric information, depending on whether, at the time of the monetary policy decision, shocks are known to some agents in the economy. In the first model, which builds once more on

[6] The model is closest to Gerlach and Smets (2000), and especially Sánchez (2005). The related literature also includes Ball (1999 and 2002), Svensson (2000), Taylor (1999), McCallum and Nelson (1999 and 2000), and Galí and Monacelli (2005).

Gerlach and Smets (2000), foreign market participants are aware of the disturbances hitting the economy, and the central bank is able to infer some of the new information - that is not directly available to it - through the analysis of exchange rate developments (asymmetric information with signal extraction). In the second model, shocks are not known to any agents at that point in time, which does not open the possibility for the central bank to deduce real-time properties of the new data (asymmetric information without signal extraction). The modeling of imperfect information allows me to analyse how robust results are to the specification of informational assumptions.

The two types of informational frictions introduced in this paper can be rationalised as capturing two possible instances in which a relevant disturbance is hitting the economy in relation to the period during which interest rates are set by the central bank. In one case, the relevant shock has just taken place, and it is therefore interesting to analyse the implications of the possibility that the authorities deduce some real-time data properties by inspecting current movements in exchange rates against the background of past shock correlations. This is the variant that I label asymmetric information with signal extraction. In the second model, the one of asymmetric information with signal extraction, the central bank is assumed not to have access to contemporaneous information. Moreover, at the time interest rate decisions are taken the current disturbances have not yet occurred. It is thus not possible in this case to allow monetary policy decisions to indirectly embody inputs from other, better informed economic agents. This second approach can be rationalised as incorporating the notion that the relevant shocks take place right after interest rates have been set.

Informational considerations have played a prominent role in the identification of structural disturbances in recent empirical work. More specifically, by incorporating an "information sector" into the analysis, identified vector autoregressions have assumed that the central bank observes some key macroeconomic variables (such as exchange rates) contemporaneously, while others (such as output and prices) are only observed with a lag.[7] The present paper could be seen as indirectly contributing to enrich the menu of identification options in two ways. First, whenever relevant, signal extraction would imply that impulse responses could be rather different from what is expected from the extreme assumption that variables are either strictly observed or strictly unobserved. In particular, the central bank's guesses regarding private sector activity (even if the latter is objectively unobserved on a contemporaneous basis) would entail completely different results depending on which shocks are expected to occur more often. Second (and alternatively), as I analyse in the asymmetric information model without signal extraction, if the most relevant shocks for monetary policy purposes occur right after the interest rate is set, any meaningful pattern for comovements between the latter variable and the exchange rate would imply a lagged, rather than a contemporaneous, relationship. In sum, which set of "reasonable" results is to be used as a benchmark in empirical analysis would depend on the specific nature of informational frictions that is most relevant to the economy in question.

The results of this paper show that full information outcomes do not appear to be robust to the presence of informational frictions. More concretely, three important differences arise between full information and the imperfect information models analysed here. For economies exhibiting expansionary or strongly contractionary depreciations, such frictions are responsible for two optimal deviations from full information outcomes: i) under asymmetric information with signal extraction, the realisation of a relatively less frequent shock (in the present case, a net export shock) leads the central bank to behave as if a more likely disturbance (a risk premium disturbance) had instead taken place; and ii) under asymmetric information without signal extraction,

[7] This empirical literature has been conducted mostly for advanced economies, including recent contributions by Kim (2003) and Sims and Zha (2004). A number of papers have started to use this approach in the context of EMEs (see, *e.g.*, Ma'ckowiak, 2003, and Aguirre and Schmidt-Hebbel, 2005).

the monetary authorities does not react on impact to shocks hitting the economy. The latter difference also implies that, for expansionary depreciations, a lower responsiveness of output to exchange rates, which has an impact on comovements between interest rates and exchange rates under full information, instead fails for any shock to affect interest rates on impact under asymmetric information without signal extraction. Finally, in the case of mildly contractionary depreciations, both asymmetric information models predict a lack of response of the central bank to aggregate demand shocks, as opposed to an offsetting movement in interest rates under full information.

The structure of the rest of the paper is as follows. Section 2 presents a simple small open economy model which assumes full information, briefly summarising the state of the art in the literature concerning the relationship between interest rates and exchange rates. In doing so, I illustrate the workings of the model by attaching numerical values to the parameters, following calibrations used in previous work for small open economies. Section 3 describes the results for the two afore-mentioned types of informational imperfections and discusses the similarities and differences with respect to the full information approach of section 2. Finally, section 4 presents some concluding remarks.

2 A simple model

In order to investigate the link between interest rates and exchange rates, let us consider a simple small open economy model. I allow for depreciations to be either expansionary or contractionary. The economy specialises in the production of a single good. Four equations describe the behaviour of the private sector:

$$\pi_t = E_{t-1}\pi_t + \alpha\left(y_t - \varepsilon_t^S\right) - \gamma(e_t - E_{t-1}e_t) \quad (1)$$

$$y_t = -\beta r_t - \delta e_t + \varepsilon_t^D \quad (2)$$

$$r_t = -E_t e_{t+1} + e_t + \varepsilon_t^f \quad (3)$$

$$r_t = R_t - E_t \pi_{t+1} \quad (4)$$

where all variables, except the interest rate, are in logarithms and expressed as deviations from steady state values. Constants have been normalised to zero. All parameters are assumed to be positive, with the exception of δ, which can adopt any real value. The value of δ is negative in a contractionary depreciation and positive in an expansionary depreciation. All shocks are of the zero-mean, constant variance, type, and are uncorrelated with each other. They are also assumed to be serially correlated, as is made clear below.

Equation (1) is a simple aggregate supply schedule which states that prices (p_t) are determined by the last period's expectations of the current price level and two other terms, namely, an output gap (y_t) term and an exchange-rate pass through term in which the real exchange rate (e_t) affects prices via import prices. Note that an increase in e_t denotes an appreciation of the real exchange rate. In (1), the more open the economy (the higher γ), the stronger the pass-through effect of exchange rate changes on consumer prices.[8] Expression (2) states that aggregate demand is decreasing in the (short-term) real interest rate (r_t). Output is also allowed to depend positively or negatively on real exchange rate as explained before.[9] Equation (3) is an uncovered interest parity condition representing foreign exchange market equilibrium under

[8] As in Sánchez (2005), the supply curve can be rationalised in terms of: a) domestic producers setting prices based on aggregate demand effects, plus an otherwise fixed mark-up over backward-looking wages; and b) sellers of foreign goods updating prices based on the evolution of the exchange rate.

[9] The Appendix sets up a framework from which the aggregate demand schedule used here can be derived.

perfect capital mobility. The shock ε_t^f is interpreted as a risk premium term. Finally, (4) is the Fisher equation defining the real interest rate.

The central bank minimises an intertemporal loss function given by

$$
\begin{aligned}
& E_t \sum_{i=0}^{\infty} \rho^i L_{i+1} \\
\text{where } L_t &= \alpha^2 (y_t - \varepsilon_t^S)^2 + \chi(\pi_t - \tilde{\pi}_t)^2 \qquad (5)
\end{aligned}
$$

Policy makers thus care about both deviations of output from its potential level, $y_t - \varepsilon_t^S$, and deviations of inflation from the target (or objective), $\pi_t - \tilde{\pi}_t$. The central bank has no incentive to surprise the private sector with inflation even in the presence of supply shocks. As a result there will be no inflation bias. In addition, the loss function implies that the central bank cares about an index of prices including both domestic and imported goods. This is consistent with standard central bank in EMEs to focus on changes in the CPI, which includes both types of goods.

I assume that the public knows α, β and δ, the distribution of the disturbances ε_t^S, ε_t^D and ε_t^f, and that it observes the nominal interest and exchange rates. I also assume that there is *full information*, in the sense that the central bank, producers and foreign exchange market participants all observe current output, prices and nominal exchange rates. With this information, and knowledge of the structure of the model, they are in a position to deduce the sources of the shocks that hit the economy. A state-contingent reaction function is then feasible. Using (1), the central bank's full information reaction function can be rewritten as

$$L = [\pi_t - E_{t-1}\pi_t + \gamma(e_t - E_{t-1}e_t)]^2 + \chi(\pi_t - \tilde{\pi}_t)^2 \qquad (6)$$

To solve the model, it is convenient to think of the central bank as choosing π_t to minimise its loss function. The first-order condition valid for optimal policy under discretion is

$$\pi_t = (1-\varphi)[E_{t-1}\pi_t - \gamma(e_t - E_{t-1}e_t)] + \varphi\tilde{\pi}_t \tag{7}$$

where $\varphi \equiv \chi/(1+\chi)$. Imposing rational expectations, we have

$$E_{t-1}\pi_t = E_{t-1}\tilde{\pi}_t \tag{8}$$

that is, expected inflation equals expected targeted inflation.

Substituting (8) back into (7), I obtain the following expression for the optimal inflation rate, π_t^{opt}:

$$\pi_t^{opt} = -(1-\varphi)\gamma(e_t - E_{t-1}e_t) + \varphi\tilde{\pi}_t + (1-\varphi)E_{t-1}\tilde{\pi}_t \tag{9}$$

The central bank thus chooses an inflation rate equal to the term capturing the effect of unexpected exchange rate fluctuations on prices, plus a weighted average of the private sector's expectations of the inflation target and the actual inflation target.

The associated inflation forecast error is

$$\pi_t - E_{t-1}\pi_t = \varphi(\tilde{\pi}_t - E_{t-1}\tilde{\pi}_t) \tag{10}$$

If the inflation target is fixed over time and is credible, the price forecast errors are zero and the variance of output is given by the variance of the supply shocks. In what follows, I assume that this is the case, that is, that the inflation target adopts a fixed and credible value of $\tilde{\pi}$. Moreover, I assume that the risk premium shock, ε_t^f, and the disturbances underlying the excess demand shock, ε_t^{xd},all follow first-order autoregressive processes with uncorrelated disturbances. In consequence, I can write: $\varepsilon_t^f = \rho_f\varepsilon_{t-1}^f + \xi_t$, in the former case, and $\varepsilon_t^{xd} = \rho\varepsilon_{t-1}^{xd} + \eta_t^{xd}$ grouping terms for shocks hitting excess demand.[10] Using (1), (2), (3) and (10) then yields[11]

$$e_t = (1-\omega)\, E_t e_{t+1} - \frac{\theta\varphi\gamma}{\alpha}(e_t - E_{t-1}e_t) + \theta\varepsilon_t^{xd} - (1-\omega)\,\varepsilon_t^f \tag{11}$$

Examination of (11) leads to the conclusion that the model has a forward solution for the case when $\mid 1-\omega \mid< 1$, and a backward solution for the case when $\mid 1-\omega \mid> 1$. In the rest of the section, I solve for each case in turn.

2.1 Forward solution for case when $\mid 1-\omega \mid< 1$

The condition $\mid 1-\omega \mid< 1$ amounts to two different ranges for the values of δ, namely, $\delta \in (-\infty, -2\beta) \cup (0, \infty)$. The forward solution to expectational difference equation (11) in the absence of bubbles is given by

$$e_t = \frac{1}{\beta(1-\rho)+\delta}\left[\varepsilon_t^{xd} - (1-\sigma)\eta_t^{xd}\right] - \frac{\beta}{\beta(1-\rho_f)+\delta}\left[\varepsilon_t^f - (1-\sigma)\xi_t\right] \tag{12}$$

where $\sigma \equiv \alpha/(\alpha+\theta\varphi\gamma)$. Next, I derive the central bank's reaction function in terms of the policy instrument, which I take to be the real interest rate. It is worth stressing, though, that, given that inflation expectations are anchored at $\tilde{\pi}$, the choice of real versus nominal interest rates proves to be insubstantial, as they are equal when measured as deviations from steady-state. Equations (3) and (12) lead to

$$r_t^{opt} = \frac{1}{\beta(1-\rho)+\delta}\left[(1-\rho)\varepsilon_t^{xd} - (1-\sigma)\eta_t^{xd}\right] + \frac{1}{\beta(1-\rho_f)+\delta}\left[\delta\varepsilon_t^f + \beta(1-\sigma)\xi_t\right] \tag{13}$$

[10] Coefficient ρ is actually a weighted average of primitive autoregressive coefficients ρ_h, ρ_x and ρ_S. (For notation, see Appendix.) In what follows, the value of ρ simply collapses to zero (in my analysis of a risk premium shock) or ρ_x (in the study of the net export shock). Similarly, ε_t^{xd} equals zero or $(1-\varpi)\eta_t^x$ for all t, respectively.

[11] See Sánchez (2005) for a more detailed derivation.

Thus, the central bank raises interest rates in response to a positive excess demand shock and an unfavourable risk premium shock. Note that (9) and (13) both describe the central bank's optimal policy. Equation (9) characterises optimal policy in terms of the goal variable of the central bank, but does not give any guidance as to how to achieve the inflation target. Under condition $\mid 1-\omega \mid < 1$, expression (13) captures how the monetary policy decision is determined. Exchange rate shocks in ε_t^f feature explicitly in the equation for the interest rate instrument, showing how monetary policy reacts to exogenous factors affecting risk premia.

I now turn to illustrating the properties of the model by means of simulations. In order to do so, I attach numerical values to the parameters, following calibrations used in previous work for small open economies. Given the lack of similar exercises for EMEs, the core of these parameter values is taken from calibrations for small open advanced economies. The values of α, β and γ are taken from Ball (1999) to equal 0.4, 0.6 and 0.2, respectively. For key parameter δ, the baseline value is chosen to equal 0.2, as in Ball (1999). In addition, I consider three other values for δ: a) $\delta = 0.1$ to assess the impact of balance sheet effects in an economy still displaying overall expansionary depreciations; b) $\delta = -1.5$, a large negative value for simulations in the present subsection satisfying $\delta < -2\beta$ (strongly contractionary depreciations); and c) $\delta = -0.1$, a small negative value for the study of mildly contractionary depreciations in the next subsection.[12] I draw from McCallum and Nelson (1999 and 2000) for parameters of shock persistence. The two I use in the present paper are $\rho_f = 0.5$ and $\rho_x = 0$. I also reset McCallum and Nelson's value for ϖ (see Appendix for notation) to 0.8 from 0.89, to capture the fact that many small open economies (especially in EMEs) are very open to international trade. Finally, in light of the absence of a similar estimate for small open economies, I use Barro and Broadbent's (1997) estimate for χ, obtained using US data.

[12] The latter value for δ is close to Cavoli and Rajan's (2005) estimate of -0.09 for contractionary-depreciation Thailand.

Their value of $\chi = 2.58$ is recalibrated to 0.41 in the present paper, taking account of the presence of α^2 in (5).

I study impulse responses of interest rates and exchanges rates to two shocks in turn, one real (a favourable net export shock raising η_t^{xd}) and the other a pure portfolio disturbance shock (an adverse risk premium shock pushing ξ_t up). In the present subsection I run simulations for three of the four cases mentioned before, namely, those of a positive δ (equalling either baseline 0.2 or 0.1) and a rather negative δ ($\delta = -1.5$ satisfying $\delta < -2\beta$).[13] Figure 1 shows, for the two alternative positive values of δ, the cumulated impulse responses to both a one percent adverse risk premium shock (top panel) and a one percent favourable net export shock (bottom panel). Figure 2 reports the corresponding cumulated impulse responses for $\delta = -1.5$.

For an economy exhibiting conventional expansionary depreciations, Figure 1 (top panel) indicates that an adverse risk premium shock drives the interest rate up and the real exchange rate down. A risk premium disturbance causes a real exchange rate depreciation with consequent inflationary effects via pass-through. Due to its standard "pro-competitiveness" impact, the currency depreciation has incipient favourable output effects. In view of the unambiguous inflationary pressures stemming from this shock (via both the exchange rate pass-through and aggregate supply channels), the monetary authority raises interest rates. In the top panel of Figure 1, the dynamic behaviour in interest rates and exchange rates is driven by the autoregressive process in the risk premium.

Figure 1 (bottom panel) shows that a favourable net export shock drives both the interest rate and real exchange rate up. This is a foreign shock that is not in itself of the financial but the real-sector variety. It can be viewed as a positive terms-of-trade or external demand shock. The hike in η_t^{xd} elicits a mix of tightening in monetary policy and exchange rate appreciation. The interest

[13] I leave the study of the remaining possible values of δ for the next subsection.

rate hike puts a limit to the increase in aggregate demand, while also being instrumental to the strengthening of the exchange rate via the UIP schedule. The latter strengthening in turn helps ease excess demand and inflationary pressures. Unlike the dynamics described for the case of a risk premium shock, interest rates and the exchange rate go back to steady-state after the initial period due to the assumption that $\rho_x = 0$.

In Figure 1 I consider two possible values for δ, namely, $\delta = 0.2$ (baseline) and a value reflecting a smaller responsiveness of output to exchange rates ($\delta = 0.1$). The comparison indicates that, for such smaller value of δ, there is less of a case for raising interest rates in the face of adverse financial shocks as given here by an increase in ε_t^f. In particular, a stronger monetary policy response is needed to stem the consequences of the disturbances on output and inflation when aggregate demand is less responsive to exchange rate developments. A different result holds when the economy is hit by a shock directly affecting the goods market, as given here by an increase in η_t^{xd}. In this case, the lower δ, the more there is a case for raising interest rates, and the exchange rate thus ends up appreciating by more in real terms. It is worth stressing that, regardless of which of the two shocks is hitting the economy, an adverse disturbance leads to a stronger depreciation, the smaller the responsiveness of aggregate demand to exchange rates. The responses to financial and real shocks described in this paragraph are strictly in line with what was found by Detken and Gaspar (2003) and Eichengreen (2005). They interpret a lower value of δ as arising from adverse balance sheet effects that produce a smaller response of output to exchange rates.

I now turn to the study of an economy exhibiting large contractionary depreciations in the sense that δ adopts a rather large negative value ($\delta < -2\beta$). Figure 2 (top panel) indicates that an adverse risk premium shock induces a rise in both interest rates and the real exchange rate. A risk premium shock causes a real exchange rate depreciation with consequent inflationary effects via the pass-through. Compared with the case of a positive δ, the shock would in addition have an incipient contractionary impact on aggregate demand. Interest rates are hiked in the present case to a point where exchange rates end up stronger. This is the adequate monetary response since a higher exchange rate both damps down inflationary pressures and stabilising the real economy by, say, strengthening balance sheets.

Figure 2 (bottom panel) reports that a favourable net export shock drives both interest rates and the real exchange rate down. In the conventional case, a positive shock that raises export demand must be offset by a stronger exchange rate. The result is the opposite here because the appreciation would exacerbate, rather than ease, the excess demand conditions in the goods market. The economy instead settles in an equilibrium characterised by an exchange-rate depreciation which reduces demand. This depreciation still accommodates for a fall in the interest rate as required by the UIP condition (augmented in this case with the risk premium shock).

Summarising, the present model allows us to reproduce all full information results emphasised in the literature. As in Eichengreen (2005) and Sánchez (2005), I find that the covariance between exchange rates and interest rates, conditional on adverse risk premium, is negative for expansionary depreciations and positive for contractionary ones. The latter result means that, in the face of adverse risk premium shocks, the authorities in economies exhibiting contractionary depreciations jack up interest to the point of even strengthening the value of domestic currency. Moreover, interest rates are predicted to eventually rise in response to an adverse net export shock in economies where $\delta < -2\beta$, and to be lowered in the case of expansionary depreciations. Finally, for the case of overall expansionary depreciations, a smaller degree of responsiveness of aggregate demand to the exchange rate implies that the latter variable ends up depreciating by more in the face of adverse financial and real disturbances. In addition, the interest rate would be hiked by more under a negative risk premium disturbance, and lowered further in the case of an adverse net export shock.

In the rest of this section I turn to the study of model results for the range of δ not yet explored, that is, the case of mildly contractionary depreciations. In doing so, my aim is to shortly reproduce Sánchez's (2005) results. The completion of full information results will pave the way for a comparison with environments of imperfect information in the next section of the paper.

2.2 Backward solution for case when $\mid 1-\omega \mid > 1$

The condition $\mid 1-\omega \mid > 1$ refers to the following range of parameter values for δ: $\delta \in (-2\beta, 0)$. In this case, the system is fundamentally backward looking, and the real exchange rate can be expressed as

$$\begin{aligned} e_t \quad = \quad & \left(\frac{1}{1-\omega}\right)^{\tau} e_{t-\tau} - \frac{1}{\beta}\sum_{s=1}^{\tau}\left(\frac{1}{1-\omega}\right)^{s-1} \varepsilon_{t-s}^{xd} + \sum_{s=1}^{\tau}\left(\frac{1}{1-\omega}\right)^{s-1} \varepsilon_{t-s}^{f} + \zeta_t \\ & + \sum_{s=1}^{\tau-1}\left(\frac{1}{1-\omega}\right)^{s-1}\left(\frac{1}{1-\omega} - \frac{\varphi\gamma}{\beta\alpha}\right)\zeta_{t-s} + \left(\frac{1}{1-\omega}\right)^{\tau-1}\frac{\varphi\gamma}{\beta\alpha}\zeta_{t-\tau} \qquad (14) \end{aligned}$$

where ζ_t is a sunspot defined by $e_t = E_{t-1}e_t + \zeta_t$. This variable is an expectational error, uncorrelated - by construction - with the information set, such that $E_{t-1}\zeta_t = 0$. Note that ζ_t is serially uncorrelated, and not necessarily correlated with the innovations of ε_t^{xd} and ε_t^{f}. In other words, this shock may not be a fundamental shock and is purely extrinsic to the economy. A number of different solutions are thus perfectly admissible, with the properties of the economy being rather different depending on the volatility of the sunspot variable and thus that of the real exchange rate via (14).

Use of (3) and (14), following the reasoning leading to expression (13) in the previous subsection, allows me to characterise the central bank's reaction function in terms of the real interest rate.

Figure 3 shows impulse responses of interest rates and exchanges rates to the same two shocks studied in the previous subsection, that is, an adverse risk premium shock and a favourable net export shock. In doing so, I neglect for simplicity the sunspot ζ_t in (14). The top panel of Figure 3 reports that an adverse risk premium shock leaves both the interest rate and real exchange rate unchanged on impact. In the absence of non-fundamental factors, e_t displays a fully backward-looking behaviour in (14). Starting from the second period, the results do not change qualitatively from those discussed for the strong variety of contractionary depreciation. The shock ε_t^f induces a rise in both interest rates and the real exchange rate. The exchange rate depreciation raises inflation via the pass-through, while also creating contractionary pressures on aggregate demand. In the end, the rise in interest rates makes exchange rates stronger, contributing to limit inflationary pressures while offsetting negative forces threatening the real side of the economy.

As can be seen in Figure 3 (bottom panel), a favourable net export shock raises the interest rate and leaves the real exchange rate unchanged in the initial period. There are two reasons for this result. First, the central bank tries to counterbalance the net export disturbance, being aware of the latter's expansionary and inflationary consequences. The initial interest rate increase succeeds in offsetting the excess demand in the goods market and thereby the inflationary pressures stemming from the shock. Second, the real exchange rate is unchanged on impact, in line with the backward-looking nature of e_t in (14). Starting from the second period, the results are qualitatively the same as those taking place on impact in the case $\delta < -2\beta$, but this time extended over a longer time horizon. The explanation for this is that the exchange rate dynamics in (14) generates persistence in both e_t and, via (3), r_t.

In sum, the correlation between exchange rates and interest rates, conditional on an adverse risk premium shock, is positive for mildly contractionary depreciations, with both of these variables going up in response to the shock.

This result is the same as previously obtained for strongly contractionary ones, except that in the case discussed in the present subsection such positive correlation is delayed to the second period onwards, with both the interest rate and real exchange rate being left unchanged on impact. The comparison between the two types of contractionary depreciations is not as straightforward in the case of a net export shock. For a favourable such shock, the dominant feature still is that of a positive correlation between exchange rates and interest rates, with both going down as a consequence of the shock. There are, however, two differences with respect to the case $\delta < -2\beta$ discussed in the previous subsection. First, in the present case when $\delta \in (-2\beta, 0)$ the falls in exchange rates and interest rates are delayed to the second period onwards, instead of taking place on impact. Second, also in this latter case, interest rates are raised and the exchange rate does not move in the initial period. In any case, economies experiencing either mildly or strongly contractionary depreciations share the result that interest rates are lowered - either on impact or at a later stage - in response to a favourable net export shock.

3 Imperfect information

In the model of section 2 it was assumed that the central bank could identify the shocks that affected the economy and the exchange rate. In practice, central banks often do not have real-time access to economic information and cannot know the sources of disturbances. In order to analyse the consequences of this real-world feature, in this section I introduce informational frictions in two ways. First, I permit only some agents to know the disturbances hitting the economy, and second, shocks are assumed not to be known to any agent in the model at the time monetary policy decisions are taken. In the former case, I assume that it is foreign market participants, whose actions are reflected in exchange rate developments, that permit the central bank to extract some real-time features of economic data even if new information is not directly available to it. Conceptually, the two types of frictions introduced belong to the category of asymmetric information. Given that in the first model no agent knows the shocks at the time interest rates are set, the type of imperfect information involved there shares some properties with frictions of the common imperfect information variety. In what follows, I group both of these models under the umbrella of asymmetric information; the first model is further labelled "with signal extraction", and the second one "without signal extraction".

In the next two subsections, I describe the two imperfect information models in turn. I then turn to the comparison of these two approaches with that of full information. In doing so, I in particular draw conclusions from the modeling of imperfect information concerning whether the previous section's results are robust to assumptions about the distribution of information across economic agents.

3.1 Asymmetric information with signal extraction

In section 3 I assumed that the central bank could identify the shocks that affected the economy and the exchange rate. It could be argued, however, that the private sector (or at least a part of it) is better informed about developments in the sphere of production. To cope with this possibility, in this subsection I explore the implications of informational barriers by assuming that the central bank does not observe current output and prices. Following Gerlach and Smets (2000), I also assume that participants in the foreign exchange market do have information about the current supply and demand shocks.[14] The exchange rate incorporates information about underlying excess demand shocks that is not otherwise available to the central bank. Expectations formed using this information set are denoted E_t^+. In line with these

[14] Information about the shocks is widespread among the private sector (except for workers), but the central bank infers some of the properties of the new data only by observing current realisations of the exchange rate.

assumptions about information, I rewrite equations (1), (2) and (3) as

$$\pi_t = E_{t-1}\pi_t + \alpha' \left(y_t - \varepsilon_t^S\right) - \gamma'(s_t - E_{t-1}^{+} s_t) \tag{15}$$

$$y_t = -\beta r_t - \delta(s_t + p_t) + \varepsilon_t^D \tag{16}$$

$$R_t = -E_t^{+} s_{t+1} + s_t + \varepsilon_t^f \tag{17}$$

where s_t is the nominal exchange rate and $\alpha' \equiv \alpha/(1+\gamma)$ and $\gamma' \equiv \gamma/(1+\gamma)$. A comparison with the full information approach of section 3 reveals that nominal exchange rates explicitly show in this subsection's set-up. The reason is that the presence of informational frictions turns necessary to further distinguish between real and nominal variables, the latter being subjected to processes of expectation formation that play an important role in the model.

I solve the model consisting of (4), (5), (15), (16) and (17). The central bank's contemporaneous inflation perception error is

$$\eta_t \equiv \pi_t - E_t\pi_t = \frac{\alpha'}{1+\alpha'\delta}\left(\eta_t^{xd} - E_t\eta_t^{xd}\right) \tag{18}$$

As with the case of common imperfect information, the central bank's optimisation, imposing rational expectations and assuming a fixed and credible inflation target, implies $E_{t-1}\pi_t = E_{t-1}\tilde{\pi}_t = \tilde{\pi}$. That is, expected inflation equals expected targeted inflation. This, together with (4), yields $r_t = R_t - \tilde{\pi}$.

Note that if the central bank observed current output or prices, it could deduce the current excess demand shock from equations (15) and (16), in which case inflation perception errors would be zero. Under the assumption that only foreign exchange market participants know current output and prices, the central bank cannot form $E_t^{+} s_{t+1}$. I make the same assumptions regarding the stochastic processes driving the shocks to the economy as in section 3. Moreover, I postulate that the signal extraction function is of the form

$$E_t\eta_t^{xd} = \lambda\left[s_t - s_t^*\right] \tag{19}$$

where λ is the response parameter that needs to be determined. To see the rationale for this signal extraction function, note that the expression in brackets in (19) represents the deviation of the current exchange rate from $s_t^* \equiv -\tilde{\pi} - p_{t-1} - \beta / \left[\beta(1-\rho_f) + \delta\right] \rho_f \varepsilon_{t-1}^f + \rho / \left[\beta(1-\rho) + \delta\right] \varepsilon_{t-1}^{xd}$. The latter expression is the (unconditionally) expected value of the nominal exchange rate when we exclude the interest rate R_t from the information set.[15] In (19), the central bank extracts information about excess demand shocks by using its knowledge of past disturbances and the current exchange rate.

Again, the model has a forward solution for the case when $\mid 1-\omega \mid < 1$, and a backward solution for the case when $\mid 1-\omega \mid > 1$. In the forward solution, the condition $\mid 1-\omega \mid < 1$ amounts to two different ranges for the values of δ, namely, $\delta \in (-\infty, -2\beta) \cup (0, \infty)$. The forward solution in the absence of bubbles can be characterised by

$$R_t = \tilde{\pi} + s_t + p_t + \frac{\beta+\delta}{\beta(1-\rho_f)+\delta} \rho_f \varepsilon_t^f - \frac{\rho}{\beta(1-\rho)+\delta} \varepsilon_t^{xd} \quad (20)$$

$$s_t = -\tilde{\pi} - p_{t-1} - \frac{\beta}{\beta(1-\rho_f)+\delta} \rho_f \varepsilon_t^f + s_1 \xi_t + \frac{1}{\beta(1-\rho)+\delta} \varepsilon_t^{xd} + s_2 \eta_t^{xd} \quad (21)$$

where $s_1 \equiv \beta z / \{[\beta(1-\rho_f)+\delta][(\beta+\delta)^2 \varsigma - z]\}$, $z \equiv (1-\varphi)\gamma'[(\beta+\delta)^2\varsigma - \beta(1+\delta)] - \gamma'\varphi[(\beta+\delta)\varsigma - \beta]/\alpha' + \lambda(\beta+\delta)$, $\varsigma \equiv (1+\alpha'\delta)/[1+\alpha'(\beta+\delta)]$ and

$$s_2 \equiv \frac{-\vartheta(1-\varphi)\gamma'[(\beta+\delta)(\beta-\delta)\varsigma + \beta(1+\delta)] - \vartheta w - (1-\vartheta\lambda)(\beta+\delta)}{(\beta+\delta)^2\varsigma - (1-\varphi)\gamma'[(\beta+\delta)^2\varsigma - \beta(1+\delta)] + w - \lambda(\beta+\delta)}$$

where $\vartheta \equiv [\beta(1-\rho)+\delta]^{-1}$ and $w \equiv \gamma'\varphi[(\beta+\delta)\varsigma - \beta]$.

[15] This amounts to conveniently subtracting from the exchange rate realisation the influence of the strategic component related to monetary policy, thereby isolating the impact on s_t of new market information.

Moreover, equilibrium inflation and output levels are

$$\pi_t = \tilde{\pi} - (1-\varphi)\gamma'(s_t - E^+_{t-1}s_t) + \eta_t \tag{22}$$
$$y_t = \varepsilon^S_t + \frac{\varphi\gamma'}{\alpha'}(s_t - E^+_{t-1}s_t) + \frac{1}{\alpha'}\eta_t \tag{23}$$

The final step is to determine λ from

$$\lambda = \frac{Cov\left(\eta^{xd}_t, s_t - s^*_t\right)}{Var\left(s_t - s^*_t\right)} \tag{24}$$

Using (19), (24) and the definition of s^*_t above, λ can be found to equal

$$\lambda = \frac{\left(s_2 + \frac{1}{\beta(1-\rho)+\delta}\right) Var(\eta^{xd})}{\left(s_1 - \frac{\beta}{\beta(1-\rho_f)+\delta}\right)^2 Var(\xi) + \left(s_2 + \frac{1}{\beta(1-\rho)+\delta}\right)^2 Var(\eta^{xd})} \tag{25}$$

That is, λ depends on the ratio of the variance of excess demand shocks relative to the variance of risk premium shocks $(Var(\eta^{xd})/Var(\xi))$. This ratio can be interpreted as an indicator of the information content of changes in the exchange rate. In particular, λ can be found to move towards zero as $Var(\eta^{xd})/Var(\xi)$ goes to zero. In this case, exogenous exchange rate shocks are dominant. The signal-to-noise ratio tends to zero and the information role of the exchange rate is lost. For this reason, the central bank relies solely on its observation of ε^{xd}_{t-1} to assess current excess demand. In the other extreme case, λ approaches $1/\{s_2 + 1/[\beta(1-\rho)+\delta]\}$ as the signal to noise ratio $Var(\eta^{xd})/Var(\xi)$ goes to infinity. In this case, exogenous exchange rate shocks are non-existent, and the central bank thus concludes that exchange rate changes are due to excess demand shocks. Since such exchange rate changes equilibrate the goods market, the central bank wants to accommodate them. The central bank disregards past excess demand shocks and relies entirely on the current exchange rate to assess current excess demand. This implies that it does not lean against current exchange rate changes.

The backward solution once more obtains under contractionary depreciations of a milder type, that is, for the range $\delta \in (-2\beta, 0)$. The system is fundamentally backward-looking, and the following expression can be derived for the nominal exchange rate in the absence of sunspots:

$$\begin{aligned} s_t &= \left(\frac{\beta+\delta}{\beta}\right)^{\tau} s_{t-\tau} + \left(\frac{\beta-\delta}{\delta}\right)\left[1-\left(\frac{\beta+\delta}{\beta}\right)^{\tau}\right]\tilde{\pi} + \frac{\delta}{\beta}\sum_{l=1}^{\tau}\left(\frac{\beta+\delta}{\beta}\right)^{l-1} p_{t-l-1} \\ &\quad -\frac{\rho}{\beta}\sum_{l=1}^{\tau}\left(\frac{\beta+\delta}{\beta}\right)^{l-1}\varepsilon_{t-l-1}^{xd} + \sum_{l=1}^{\tau}\left(\frac{\beta+\delta}{\beta}\right)^{l-1}\varepsilon_{t-l}^{f} \end{aligned} \tag{26}$$

Given that the exchange rate is predetermined in the backward solution, $E_t\eta_t^{xd} = 0$. Moreover, the equilibrium inflation and output levels equal $\pi_t = \tilde{\pi} + \eta_t$ and $y_t = \varepsilon_t^S + \eta_t/\alpha'$, respectively.

A comparison between (26) and the corresponding expression under full information, that is (14), reveals both points in common and differences. The two expressions differ in that, while both are backward-looking in nature, the former is written in terms of the nominal exchange rate, while the latter is written in terms of the real one. For this reason, an excess demand shock affecting π_t via η_t will have a contemporaneous effect on the real exchange rate under asymmetric information with signal extraction. This is not the case under full information. In the latter case, any shock fails to contemporaneously affect the real exchange rate, which is a backward-looking variable. In the face of a risk premium shock, the real exchange rate does not react on impact in either the full information case or that analysed in this subsection. Equations (14) and (26) also have in common the implication that the real exchange rate eventually returns to steady state. The latter results is easy to see in (14) because this expression is directly written in terms of the real exchange rate e_t. But it also holds in (26). To see this, first note that the effect of a given shock will tend to fade away over time. Second, note that $e_t \equiv s_t + p_t$, so that prices affect the real exchange rate by a factor of $1+(\delta/\beta)\sum_{l=1}^{\tau}\left[(\beta+\delta)/\beta\right]^{l-1}$, which tends in the limit to 0.

3.2 Asymmetric information without signal extraction

The previous subsection has relaxed the assumption of full information by introducing one type of asymmetric informational friction. In this subsection I examine the other possible case where information is not available to any agent in the economy at the time of the monetary policy decision. At that point in time, neither the central bank nor the private sector observes current output and prices, and the former cannot thus infer macroeconomic disturbances. To incorporate this possibility into the model, I assume that shocks affecting endogenous variables in period t take place right after the central bank forms expectations and takes its decision. The current exchange rate is, like output and prices, contemporaneously unknown to the central bank.[16] As before, I label expectations formed using the implied limited information set simply by E_t and those of informed agents by E_t^+. After the central bank action is taken, the private sector observes shocks. Producers take decisions on prices and output, and the exchange rate is set to clear the foreign exchange market. All these private sector actions occur too late for the central bank to factor them in during its current period's decision, but they are known to the policymaker at the time of the next monetary policy move.

As with the asymmetric information set-up of subsection 4.1, nominal exchange rates are to be explicitly handled in order to solve the model. The model still consists of equations (4), (5), (15), (16) and (17). However, the solution needs to incorporate the specific timing of information described in the previous paragraph. In particular, the nominal exchange rate s_t needs to be replaced by $E_t s_t$ when it comes to modeling the central bank's expectations

[16] This might seem odd given that information on exchange rates is easily available. The rationale for this setup is that I try to incorporate, in the context of a discrete-time framework, the notion that there is an institutional constraint in the timing of interest rate decisions (such as a fixed time interval between such decisions) as opposed to the higher frequency of shocks and changes in prices, output and exchange rates in real-world situations.

and actions. Since the central bank does not observe current prices, I assume that it optimises the objective function by choosing the perceived inflation rate. The contemporaneous inflation perception error is

$$\eta_t \equiv \pi_t - E_t\pi_t = \frac{1}{1+\alpha'\delta}\left[\alpha'\eta_t^{xd} - (\alpha'\delta + \gamma')(s_t - E_t s_t)\right] \tag{27}$$

The central bank's optimisation, imposing rational expectations and assuming a fixed and credible inflation target, implies $E_{t-1}\pi_t = E_{t-1}\tilde{\pi}_t = \tilde{\pi}$. That is, expected inflation equals expected targeted inflation. This, together with (4), yields $r_t = R_t - \tilde{\pi}$.

The equilibrium inflation and output levels equal

$$\begin{aligned} \pi_t &= \tilde{\pi} + \eta_t & (28) \\ y_t &= \varepsilon_t^S + \frac{\gamma'}{\alpha'}(s_t - E_{t-1}^{+}s_t) + \frac{1}{\alpha'}\eta & (29) \end{aligned}$$

where I have used the result that $E_t s_t = E_{t-1}^{+}s_t$.

I make the same assumptions regarding the stochastic processes driving the shocks to the economy as in section 3 and subsection 4.1. Using (4), (15), (16), (17), (27) and (28), the equilibrium nominal exchange rate can then be found to equal

$$s_t = E_{t-1}^{+}s_t - \varepsilon_t^f + \frac{1}{\beta}\left[(\beta - \delta)\,\tilde{\pi} - \delta p_{t-1} + +\rho\varepsilon_{t-1}^{xd} - \delta E_t s_t\right] \tag{30}$$

Once more, the model has a forward solution for the case when $\mid 1-\omega \mid < 1$, and a backward solution for the case when $\mid 1-\omega \mid > 1$. In the forward solution, the condition $\mid 1-\omega \mid < 1$ amounts to two different ranges for the values of δ, namely, $\delta \in (-\infty, -2\beta) \cup (0, \infty)$. The forward solution in the absence of bubbles can be characterised by

$$R_t = \tilde{\pi} + \frac{\delta}{\beta(1-\rho_f)+\delta}\rho_f \varepsilon^f_{t-1} + \frac{1-\rho}{\beta(1-\rho)+\delta}\rho\varepsilon^{xd}_{t-1} \quad (31)$$

$$s_t = -\tilde{\pi} - p_{t-1} - \frac{\beta}{\beta(1-\rho_f)+\delta}\varepsilon^f_t + s_3\xi_t + \frac{\rho}{\beta(1-\rho)+\delta}\varepsilon^{xd}_{t-1} + s_4\eta^{xd}_t \quad (32)$$

where $s_3 \equiv -x/[\beta(1-\rho_f)+\delta]$, $s_4 \equiv [1-(1-\rho)\alpha'(\beta+\delta)]/\{(1-\gamma')[\beta(1-\rho)+\delta]\}$ and $x \equiv \{\delta[1+\alpha'(\beta+\delta)]+\gamma'\beta\}/(1-\gamma')$.

The backward solution obtains when $\mid 1-\omega \mid > 1$. This condition refers to contractionary depreciations of a milder type, that is, the range $\delta \in (-2\beta, 0)$.

In the absence of sunspots, the nominal exchange rate is found to still be given by (26). The interpretation is, however, somewhat different. In subsection 4.1 the central bank observes the current exchange rate, but given that the latter is purely backward-looking under mildly contractionary depreciations, it does not reveal any fresh information on the shocks hitting the economy. In the present subsection, the monetary authorities do not observe the exchange rate, with the same outcome that they ignore the current state of the economy. Finally, equilibrium inflation is again given by (28), while equilibrium output simplifies further from (29) to $y_t = \varepsilon^S_t + \eta_t/\alpha'$.

3.3 Comparison with the full information case

This subsection makes a comparison of results obtained under imperfect information with the full information case. In making this comparison, I relate Figures 4 through 6 (the full information case) to Figures 7 through 9 (asymmetric information case) on the one hand, and Figures 10 through 12 (common imperfect information case) on the other. In addition to the parameter values used for calibration in section 3, simulation analysis under imperfect information also requires some values for the variances of the shocks. These extra parameter values, taken from McCallum and Nelson (2000), are: $Var(\xi) = 0.04^2$, $Var(\varepsilon^S) = 0.007^2$, $Var(\varepsilon^d) = 0.01^2$ and $Var(\varepsilon^x) = 0$ (see Appendix for notation).

Let us start by comparing the full information case with that of asymmetric information with signal extraction. Under the latter assumption, Figure 4 shows, for the two alternative positive values of δ, the cumulated impulse responses to risk premium and net export shocks, corresponding to Figure 1 under full information. Figures 5 and 6 report the corresponding cumulated impulse responses for $\delta = -1.5$ and $\delta = -0.1$, thereby being comparable to Figures 2 and 3, respectively.

In the case of an economy exhibiting standard expansionary depreciations, Figure 4 indicates that the simulation results under asymmetric information with signal extraction are little or considerably changed from those found for the full information case (see Figure 1) depending on which of the two shocks are realised. In the top panel of Figure 4, we see that an adverse risk premium shock drives the interest rate up and the real exchange rate down. Moreover, under a lower response of output to exchange rates (a lower δ), the policymaker raises interest rates by a smaller amount in the face of an adverse financial shock of the same magnitude. That is, I now obtain qualitatively the same results as under full information, with informational frictions only accounting for small quantitative differences. Such minor changes in response to a rise in ε^f are understandable. In the previous paragraph, I have assumed a large variability of the risk premium shock relative to that of excess demand for my baseline simulations. Therefore, the central bank will infer that the shock driving foreign exchange market developments is likely to be a risk premium shock, which is as we know the case. With regard to the corresponding comparison for net export shocks, we instead see that the bottom panel of Figure 4 stands in sharp contrast with the same panel of Figure 1. In the latter panel, which obtains under full information, a favourable net export disturbance induces rises in both interest rates and the real value of domestic currency. In Figure 4, which is produced under the assumption of asymmetric information with signal extraction, an exogenous increase in net exports leads to the opposite result: both interest rates and the real exchange rate fall as a result of the shock. The reason for this difference resides exactly on the same factor that is responsible for the similarity of results under risk premium shocks. In the present case, based on exchange rate developments and past shock correlations, the central bank is led to think that the disturbance is more likely to be a favourable risk premium shock than a positive net export shock. Since the former disturbance would reduce inflation and be contractionary, the central bank cuts interest rates to the point - given the baseline set of parameter values - of even weakening the exchange rate. One corollary of this comparison of results is that there is a trade-off involved in how asymmetric information with signal extraction relates to full information. The closer results are for one type of shock (under the present parameter values, the risk premium shock), the sharper the contrast with the other type (in the current environment, the net export shock, that is, an excess demand disturbance). It is worth mentioning that, with a different ranking of the variability in the two shocks in question, the specific results would be reversed, but the trade-off in the comparability of results across models would still obtain.[17]

I now turn to examining the role of the responsiveness of output to the exchange rate. Figures 1 and 4 have in common that: a) the exchange rate exhibits a larger variation under when δ equals 0.1 than when $\delta = 0.2$ (in particular depreciating by more in the first case under adverse realisations of either financial or real disturbances); and b) the interest rate rises by less under adverse risk premium shocks and is lowered by more in the face of favourable

[17] That is, the results under the assumption of asymmetric information with signal extraction would resemble those obtained under full information in the face of net export shocks, and this at the expense of the similarity found for risk premium disturbances in the baseline scenario.

net export disturbances.[18] It is worth looking at this conclusion regarding the role of δ against the background of the discussion in the previous paragraph: The latter showed that the results for risk premium shocks are qualitatively the same as those found under full information, while for net export shocks the responses themselves are of opposite signs.

The comparison between asymmetric information with signal extraction and full information follows a similar pattern in the case of strongly contractionary depreciations (Figure 5 *versus* Figure 2). In both cases, δ adopts a rather large negative value ($\delta < -2\beta$). Once more, how much results are affected by informational frictions depends on which of the two disturbances hit the economy. As obtained under full information, Figure 5 (top panel) indicates that an adverse risk premium shock induces a rise in both interest rates and the real exchange rate. Instead, the results found under asymmetric information with signal extraction differ markedly from the full information ones in the face of net export disturbances. Figure 5 (bottom panel) shows that a favourable net export shock drives both interest rates and the real exchange rate up, as opposed to down in the corresponding panel of Figure 2. The reason for this difference lies, as discussed for Figure 4 (bottom panel), in the signal extraction problem facing the central bank. Using their knowledge about current exchange rate movements and past history, the central bank judges that the shock is more likely to be a favourable risk premium shock than a positive net export shock.

For mildly contractionary depreciations, a comparison of Figure 6 with Figure 3 permits us to assess whether asymmetric information results (Figure 6 for cases either with or without signal extraction) differ from those obtained under full information (Figure 3). To start with, the reason why results for the two imperfect information models coincide here is better understood in

[18] One interesting difference between the bottom panels of Figures 1 and 4 is that the interest rate and the exchange rate are (in deviations from steady state) identical. This can be seen in equation (20) by setting the risk premium shock to zero and, in line with my calibrations, ρ_x and thus ρ to zero as well.

two steps. First, in neither case does the central bank observe the shocks presently hitting the economy. Second, in neither case do the authorities learn anything about relevant contemporaneous shocks: In the model without signal extraction, the central bank cannot deduce anything about the current state of the economy prior to the monetary policy decision simply because the private sector is still unaware of the shocks, while in the case with signal extraction, even if the monetary authorities observe the current exchange rate, the latter variable is not informative about the contemporaneous economic conditions because it is determined in a backward-looking fashion. The comparison between Figures 3 and 6 indicates that informational asymmetries do not have any impact on the results in the face of a risk premium shock, while they make a difference in the case of net export disturbances. The reasons for this are the following. Under either imperfect information model, the nominal exchange rate is backward looking, and given that the central bank does not react on impact, the first-period behaviour of the real exchange rate depends on whether the disturbance affects the price level. It turns out that the latter is unchanged following a risk premium disturbance, but it increases in response to a favourable net export shock. This implies that in the initial period the former shock leaves the real exchange rate unaffected, while the latter shock induces a real exchange rate appreciation. The top panels of Figures 3 and 6 are identical: Regardless of whether informational frictions are in place, a risk premium disturbance leaves the interest rate and the real exchange rate both unaffected on impact. The ensuing dynamics is also the same, again regardless of whether information is full or imperfect. Instead, the bottom panels of Figures 3 and 6 are different, revealing that informational asymmetries leave their mark on the results. As mentioned before, a favourable net export shock leads to a real exchange rate appreciation on impact under imperfect information, while the interest rate stays at its baseline level. This is not the case under full information, in which situation the real exchange rate

- which is directly observed by the authorities - is backward-looking and in particular initially unresponsive. The central bank understandably reacts to the expansionary and inflationary shock in question by tightening monetary policy. Following the initial period, the dynamics following this net export shock are also different between the full and imperfect information models. Under full information, both the interest rate and the real exchange rate fall below baseline before eventually going back to steady state. Instead, asymmetric information models predict that the interest rate will be higher and the real exchange rate will remain stronger before starting their convergent paths to long run levels.[19]

We have seen that Figure 6 reports results for mildly contractionary depreciations under both types of asymmetric information approaches. What is left now is the analysis of asymmetric information without signal extraction for economies displaying expansionary depreciations ($\delta > 0$) or strongly contractionary depreciations ($\delta < -2\beta$). Simulations for these two cases are presented in Figures 7 and 8, respectively.

In Figure 7, the top panel shows impulse responses for an economy displaying expansionary depreciations to an adverse risk premium shock under asymmetric information without signal extraction. The main pattern here is that the interest rate rises and the exchange rate depreciates, the same results obtained under full information (Figure 1, top panel).[20] The only difference with respect to full information outcomes is circumscribed to the reaction of the interest rate on impact: it does not move under asymmetric information without signal extraction, while it goes up in the case of full information. The bottom panel of Figure 7 indicates that, in the face of a net export shock, the

[19]One last point concerning the comparison of models for mildly contractionary depreciations refers to the role of non-fundamental behaviour. In this area, there is basically no difference between the three different approaches studied here. The theoretical analyses presented above confirm the potential relevance of non-fundamental behaviour even after relaxing the assumption of full information.

[20]For this same shock, the similarity of results carries over to the case of asymmetric information with signal extraction (Figure 4, top panel).

results mirror those obtained under full information for the real exchange rate, which appreciates in response to the emergence of a positive excess demand for goods. However, the central bank's lack of contemporaneous information implies that interest rate is left unchanged, as opposed to hiked under full information. Finally, for both shocks, assuming that $\delta = 0.1$ instead of $\delta = 0.2$ has, in the present case, a different effect on results for interest rates on impact. More concretely, changing δ here has no consequences whatsoever for interest rates in the initial period, which stay at zero under any of the two shocks considered. Other than that, reactions of impulse responses in Figure 7 to a smaller value of δ are broadly similar to those obtained under full information: a) the exchange rate fluctuates by a wider margin in reaction to either shock; and b) interest rates are, after the initial period, raised by less in the face of adverse financial disturbances and cut by more under real shocks.

For the case of strongly contractionary depreciations, Figure 8 presents in its top panel the reaction of interest rates and exchange rates to a negative financial disturbance under asymmetric information without signal extraction. Interest rates (after the initial period) go up and the exchange rate strengthens in real terms, the same results obtained under full information (Figure 2).[21] As with Figure 7 (top panel), the only difference is circumscribed to the reaction of the interest rate on impact: it is left unchanged in the case of asymmetric information without signal extraction, while it rises under full information.. The bottom panel of Figure 7 indicates that, in the face of a net export shock, the results mirror those obtained under full information for the real exchange rate, which depreciates in response to the emergence of a positive excess demand for goods. Instead, given that monetary authorities lack information about current shocks, the interest rate does not move, as opposed to being cut in the case of full information.

In sum, I find that full information results do not appear to be robust to

[21] Once more, for this same disturbance, results are equally comparable to those found under asymmetric information with signal extraction (Figure 5).

the presence of informational frictions. For economies exhibiting expansionary or strongly contractionary depreciations, such frictions are responsible for two optimal deviations from full information outcomes: i) under asymmetric information with signal extraction, the realisation of a relatively less frequent shock leads the central bank to behave as if a more likely disturbance had instead taken place; and ii) under asymmetric information without signal extraction, the monetary authorities does not react on impact to shocks hitting the economy. The latter difference in results also implies that, for expansionary depreciations, a lower responsiveness of output to exchange rates, which has an impact on comovements between interest rates and exchange rates under full information, instead fails for any shock to affect interest rates on impact under asymmetric information without signal extraction. Finally, in the case of mildly contractionary depreciations, both asymmetric information models predict a lack of response of the central bank to aggregate demand shocks, as opposed to an offsetting movement in interest rates under full information.

4 Concluding remarks

The present paper studies the comovements between interest rates and exchange rates in small open economies under flexible exchange rates, comparing situations where information is full with two alternative models of imperfect information. The latter distinction has not been made in the previous related literature, despite the obvious real-life feature of economic decisions that they are taken under a less-than-perfect understanding of the current state of affairs. In undertaking this study, I also analyse both economies for which depreciations are expansionary and contractionary. The latter is an attempt to bridge the gap between standard analyses and the empirical evidence commonly found in emerging economies.

The results of this paper allow us to identify the following three important differences between full and imperfect information. The first two of these differences are specific to each of the two asymmetric information models studied here (that is, either with or without signal extraction), while the third is common to both such models. First, in the case of asymmetric information with signal extraction the policymaker's assessment of the latest exchange rate data based on past statistical comovements will determine by how much the results deviate from those obtained under full information. In the baseline scenarios for cases of expansionary or strongly contractionary depreciations, I obtain qualitatively the same results for a risk premium disturbance, but very different ones for net export shock. For the latter type of disturbance, when the informational friction in question is present the central bank will still be led to think that the shock is more likely to be a risk premium shock. As a result, under expansionary (strongly contractionary) depreciations the interest rate will be lowered (raised) and the exchange rate will weaken (strengthen). Exactly the opposite patterns hold under full information. As a corollary of these comparisons, one can conclude that there is a trade-off involved in how asymmetric information with signal extraction relates to full information. The closer results are for one type of shock (under the present parameter values, the risk premium shock), the sharper the contrast with the other type (in the current environment, the net export shock, that is, an excess demand disturbance). If a ranking of the variability in the two shocks in question is reversed from baseline, the specific results would also be swapped, while the trade-off in the comparability of results across models would still obtain.

Second, in the case of asymmetric information without signal extraction, a difference with respect to full information arises as to how monetary policy reacts on impact to both shocks. This applies to either a risk premium or a net export disturbance, and for economies exhibiting either expansionary or strongly contractionary depreciations. While the interest rate is left unchanged under asymmetric information without signal extraction, it moves under full information - the concrete direction depending on which shock happens to occur. The fixity of interest rates on impact under the informational friction in question simply reflects the assumption that the central bank does not have access to relevant contemporaneous data. At the time of monetary policy decisions, this data is not even available to other agents, from whose actions the authorities could indirectly deduce some of the real-time data properties. Finally, for both types of shocks, assuming a smaller responsiveness of output to exchange rates in the present case implies a different outcome in terms of how interest rates react on impact. More concretely, changing that parameter has no consequences whatsoever for interest rates on impact under asymmetric information without signal extraction, which stay at zero under any of the two shocks considered. This compares with an active initial monetary policy response - one that does depend on which shock occurs - under full information.

Third, for economies showing mildly contractionary depreciations the responses to net export shocks are different for the entire path of exchange rates and interest rates when we compare the cases of asymmetric information (both with and without signal extraction) with that of full information. This difference is easy to grasp. Under either imperfect information model, the nominal exchange rate is backward looking, and given that the central bank is initially unresponsive, the first-period behaviour of the real exchange rate depends on whether the shock has an impact on the price level. This implies that a favourable net export shock leads to a real exchange rate appreciation on impact, while the interest rate stays at its baseline level. This is not true under full information, in which case the real exchange rate - which is directly observed by the authorities - is initially unresponsive. The monetary authorities react to the shock, which is expansionary and inflationary, by raising the interest rate. After the initial period, the dynamics following a net export disturbance is also found to differ between the full and imperfect information models. Under full information, both the interest rate and the real exchange rate fall below baseline before eventually going back to steady state. Instead, asymmetric information models predict that the interest rate will be higher and the real exchange rate will remain stronger before starting their convergent paths to long run levels.

One last point worth mentioning refers to whether non-fundamental dynamics play a different role depending on the type of informational assumptions used. My conclusion is that there is basically no difference between the three different approaches studied here. The theoretical analyses presented above confirm the potential relevance of non-fundamental behaviour even after relaxing the assumption of full information. While in my study sunspots were neglected for simplicity, future work would benefit from an assessment as to whether non-fundamental dynamics are empirically relevant and, if so, what specific patterns they adopt in practice.

Appendix: Derivation of domestic demand schedule

Here I propose a framework from which the domestic demand equation of section 2 can be derived. The derivation starts with the resource constraint:

$$y_t = \varpi d_t + (1 - \varpi) x_t \tag{A.1}$$

where y_t is output, d_t is domestic spending, x_t is net exports, and ϖ is the weight of domestic demand in total output. Equation (A.1) states that output is the weighted sum of domestic spending and net exports.

I assume the variables in (A.1) are determined by

$$d_t = -\beta r_t + \delta_1 e_t + \varepsilon_t^d \tag{A.3}$$

$$x_t = -\delta_2 e_t + \varepsilon_t^x \tag{A.5}$$

Domestic spending depends on the real interest rate and on shocks such as shifts in fiscal policy or consumer confidence (ε_t^d). Moreover, it is assumed to exhibit a non-negative relationship with the real exchange rate - that is, $\delta_1 \geq 0$ - owing to balance sheet-type effects. Net exports depend negatively on the real exchange rate and shocks capturing unexpected shifts in external demand, trade policy or foreign competition (ε_t^x). Both ε_t^d and ε_t^x are serially uncorrelated and are assumed to be uncorrelated with each other. Substituting equations (A.3) and (A.5) into (A.1) leads to (2), where $\varepsilon_t^D \equiv \varpi\varepsilon_t^d + (1-\varpi)\varepsilon_t^x$ is the composite shock hitting domestic demand, and the sign of $\delta \equiv \varpi\delta_1 + (1-\varpi)\delta_2$ is as follows:

$$\delta \begin{cases} > 0 \quad (i.e.,\ \varpi\delta_1 < (1-\varpi)\delta_2) & \text{for expansionary depreciations} \\ < 0 \quad (i.e.,\ \varpi\delta_1 > (1-\varpi)\delta_2) & \text{for contractionary depreciations} \end{cases}$$

The non-standard contractionary depreciation case may result if the depreciation depresses domestic demand (say, by weakening the economy's balance sheets) with more intensity that it renders domestic goods more competitive. The conventional expansionary depreciation takes place in the opposite case.

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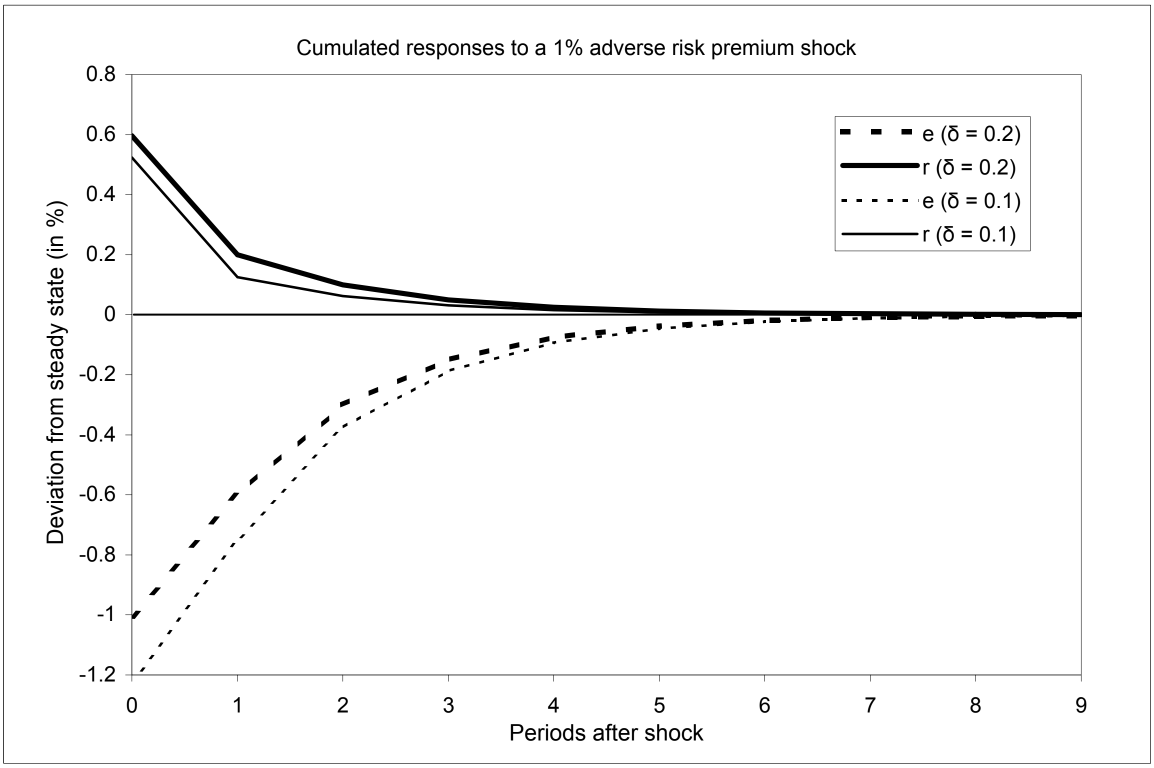
Figure 1. Full information case: Impulse responses of interest rate and real exchange rate (δ > 0)



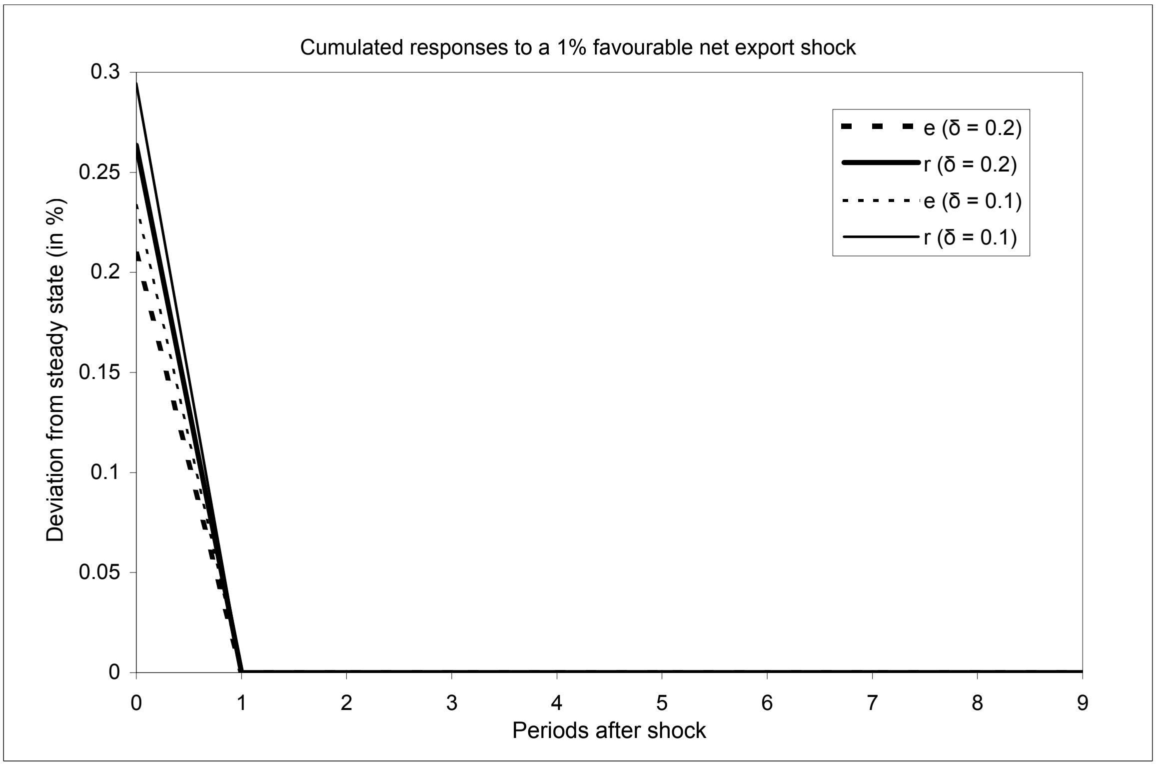
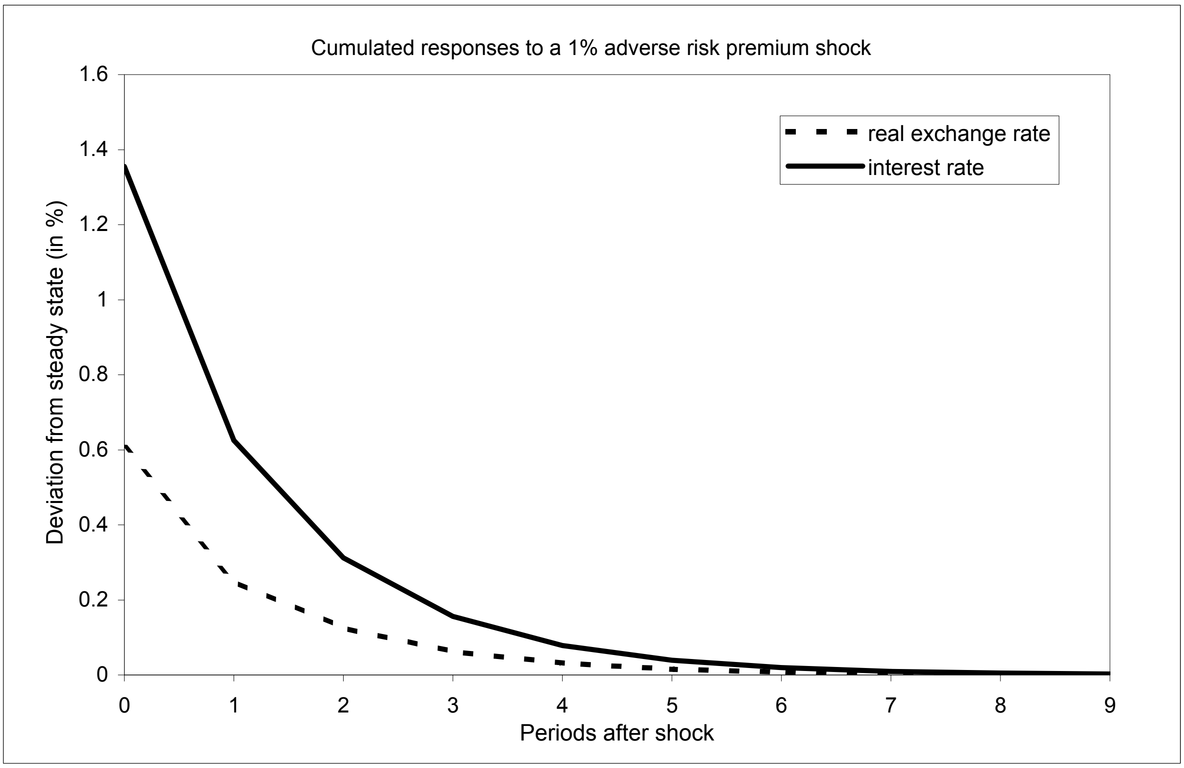


Figure 2. Full information case: Impulse responses of interest rate and real exchange rate (δ = -1.5)



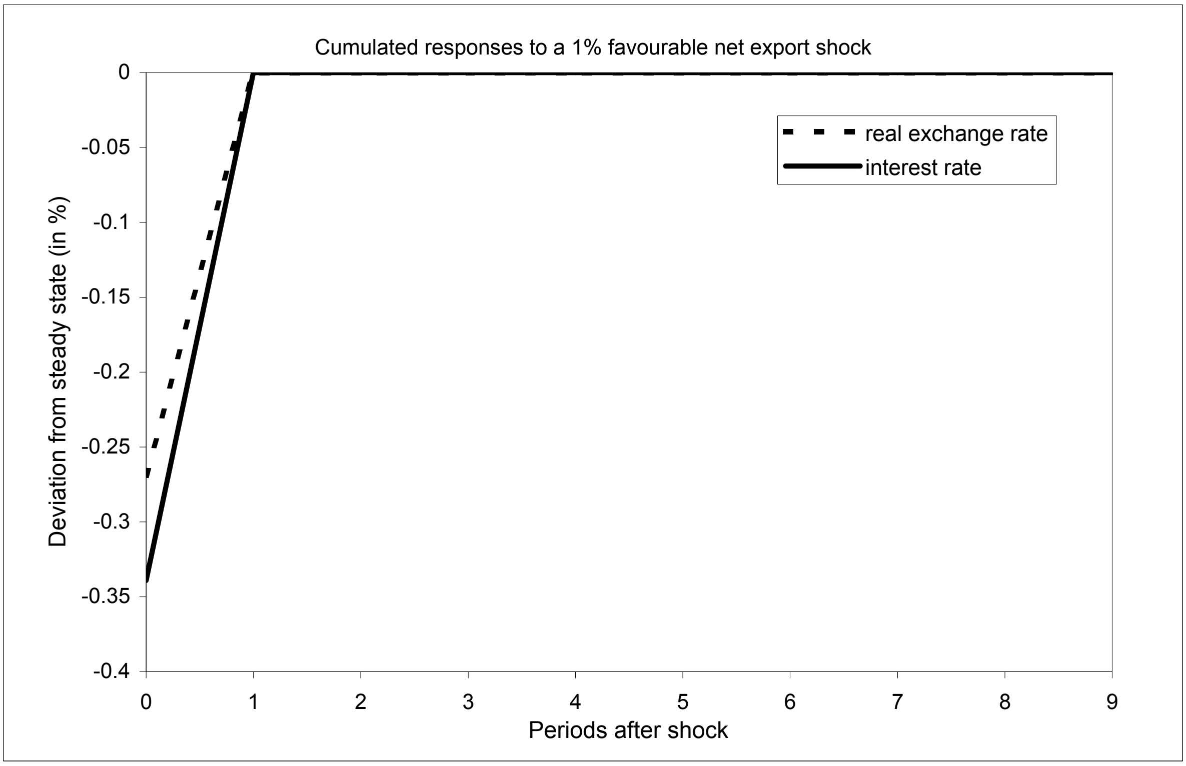
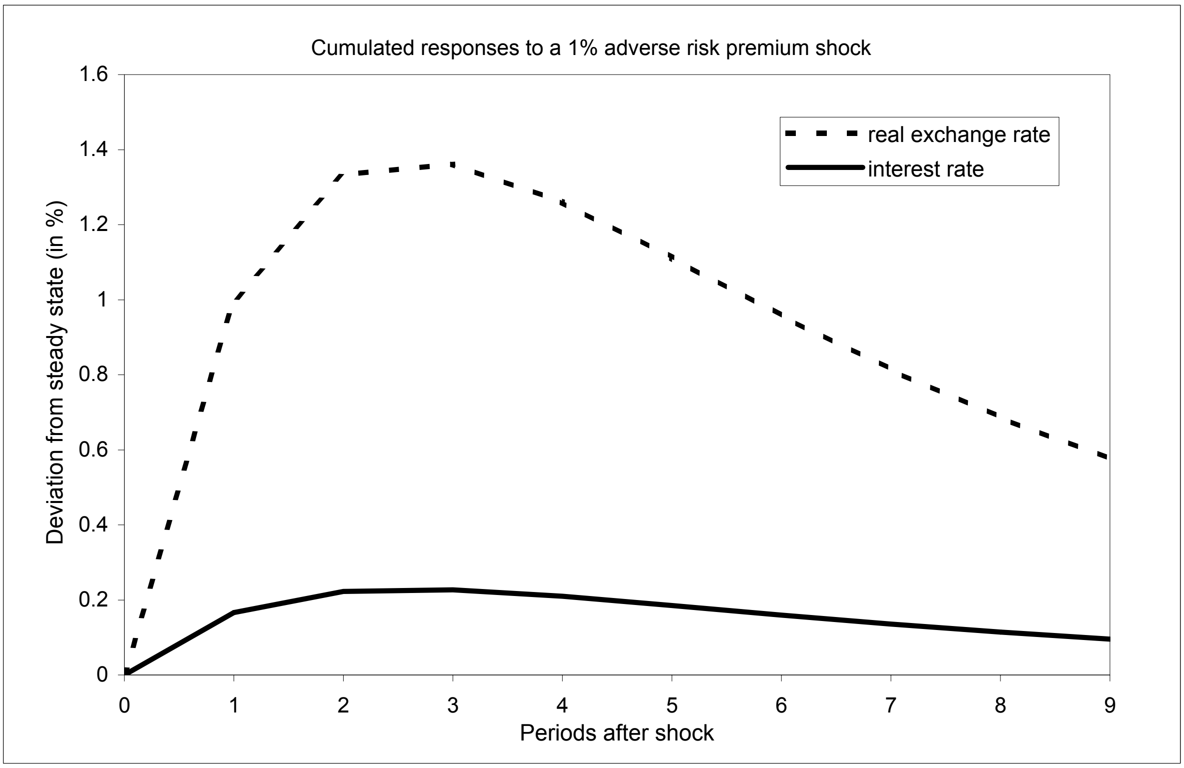


Figure 3. Full information case: Impulse responses of interest rate and real exchange rate (δ = -0.1)



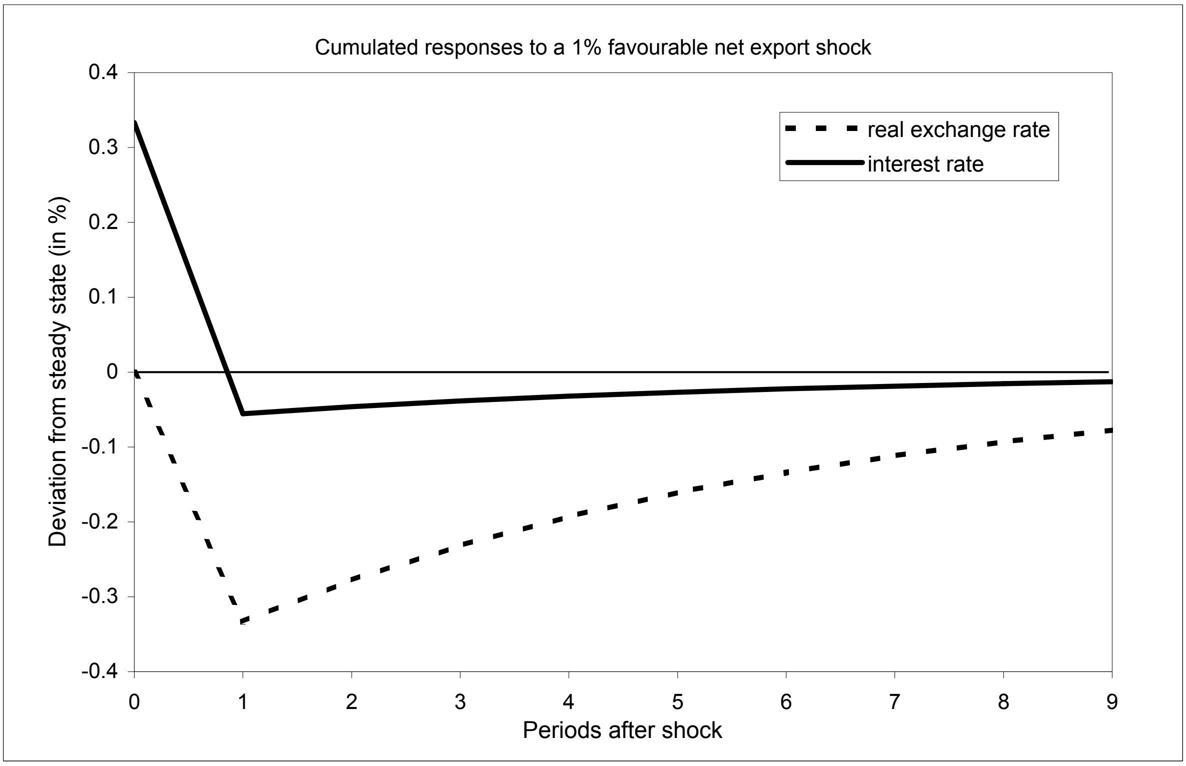
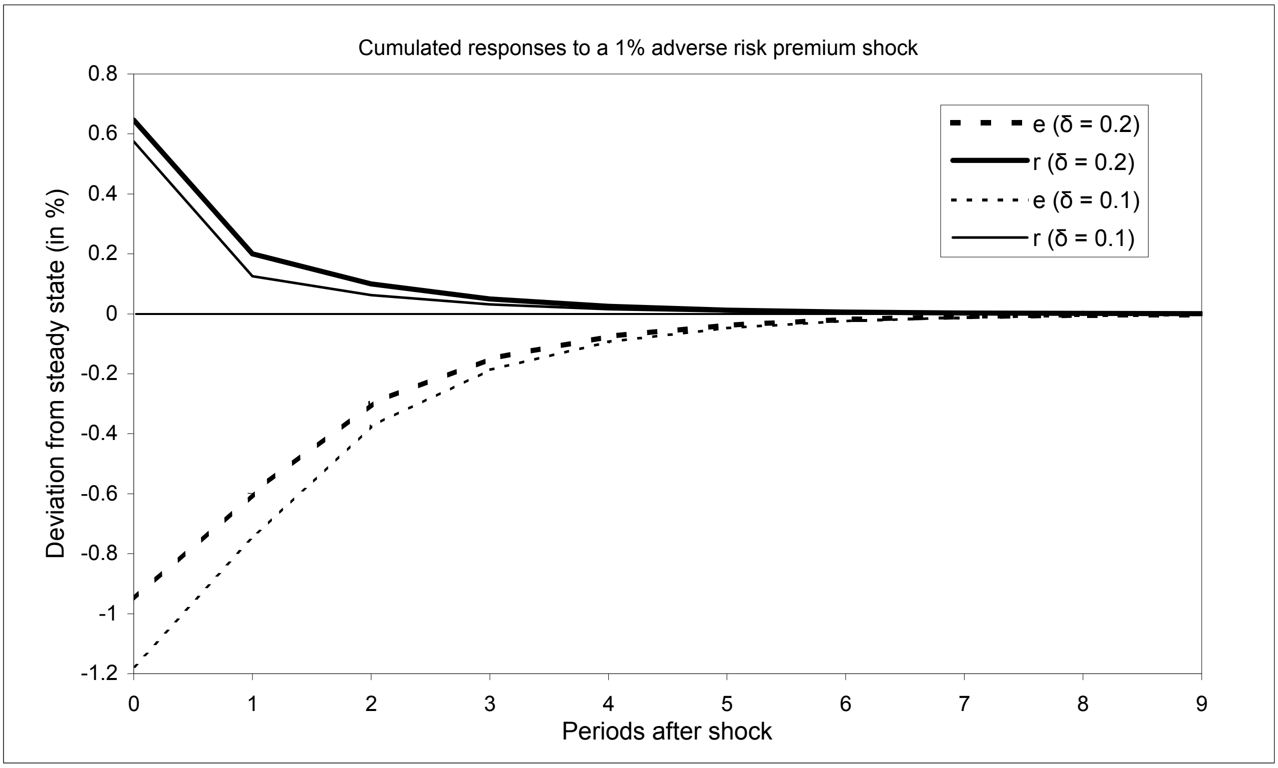


Figure 4. Asymmetric information with signal extraction: Impulse responses of interest rate and real exchange rate (δ > 0)



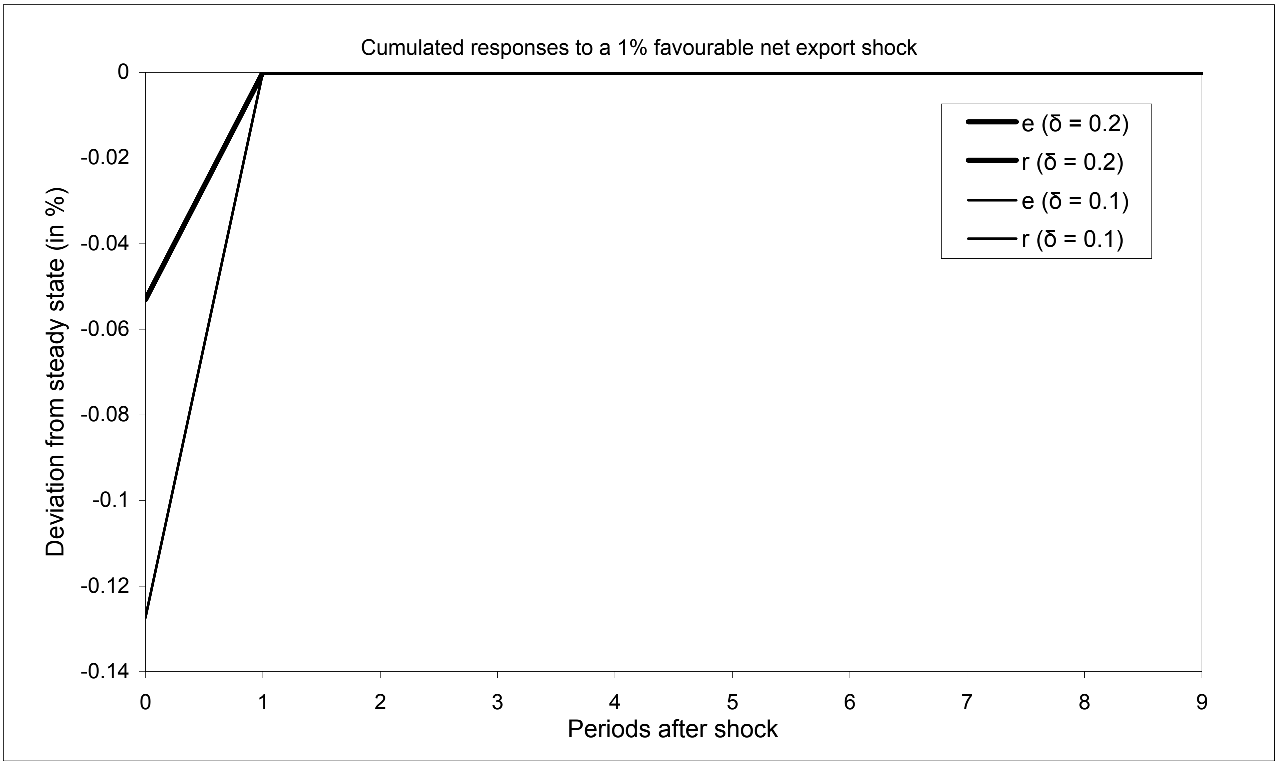
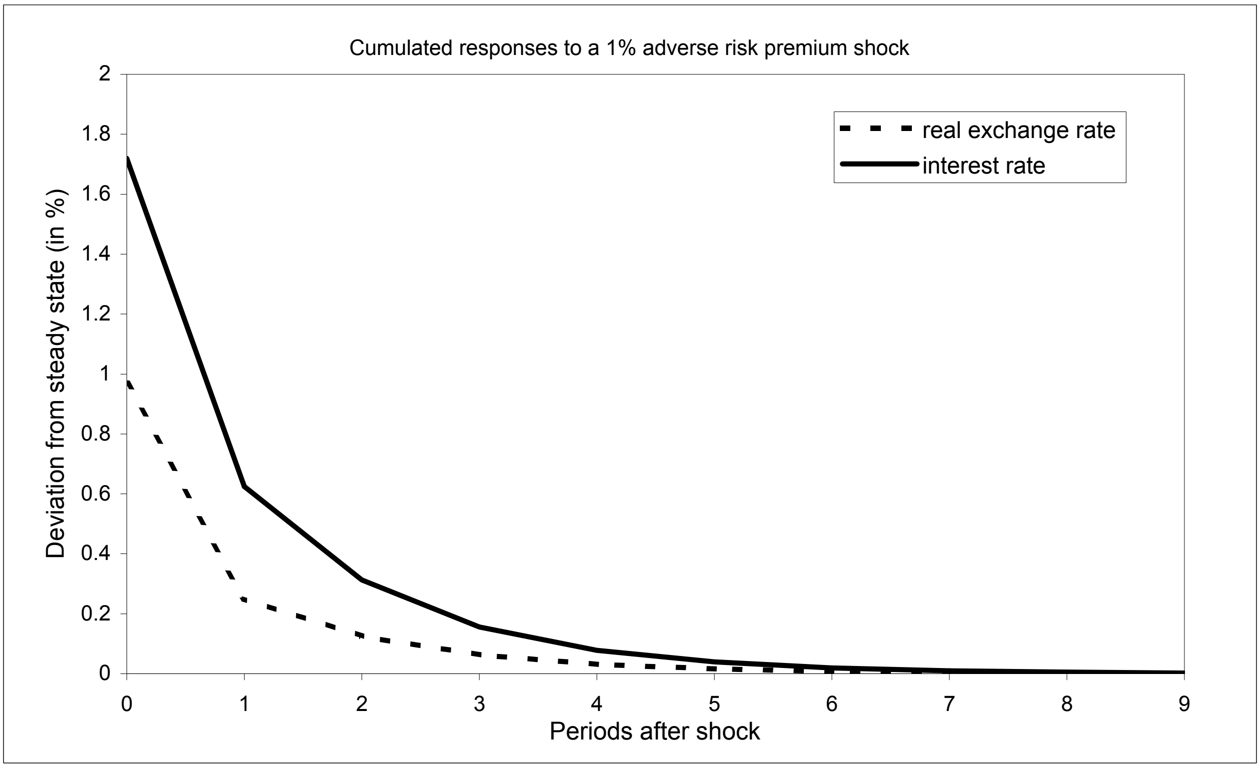


Figure 5. Asymmetric information with signal extraction: Impulse responses of interest rate and real exchange rate (δ = -1.5)



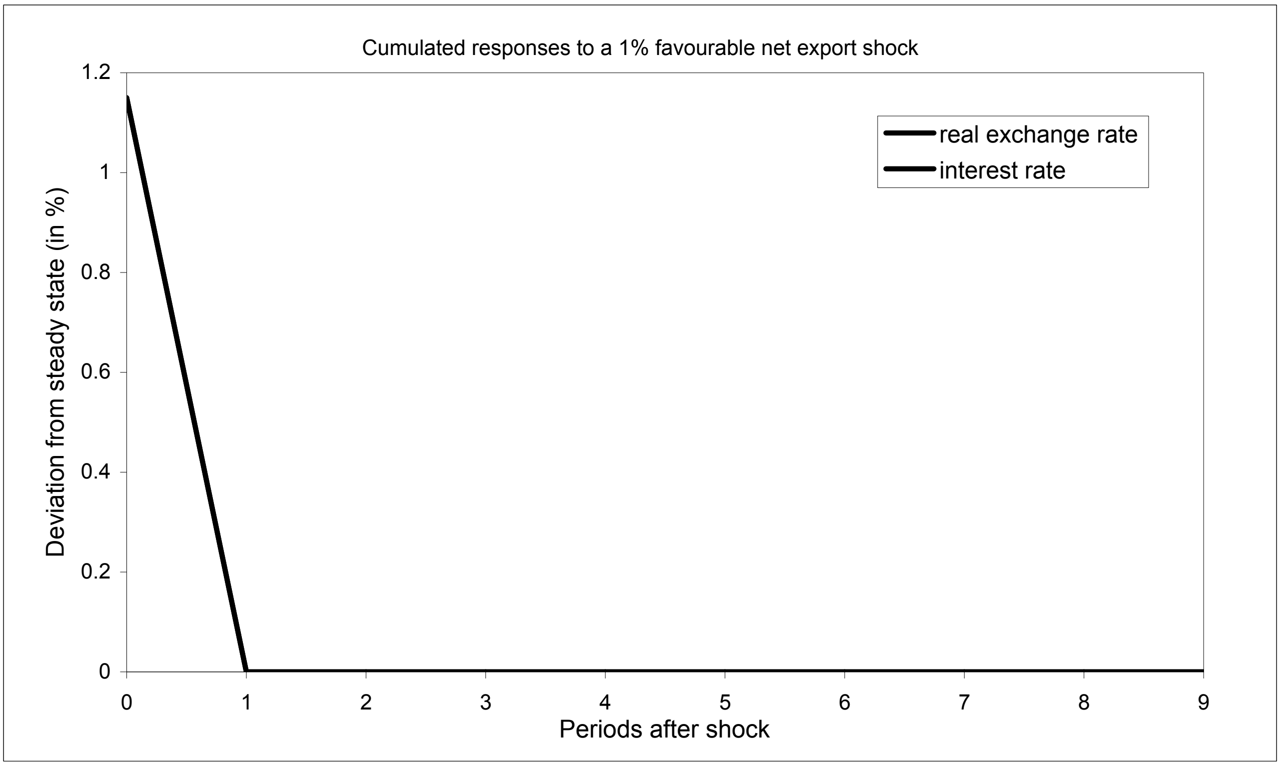
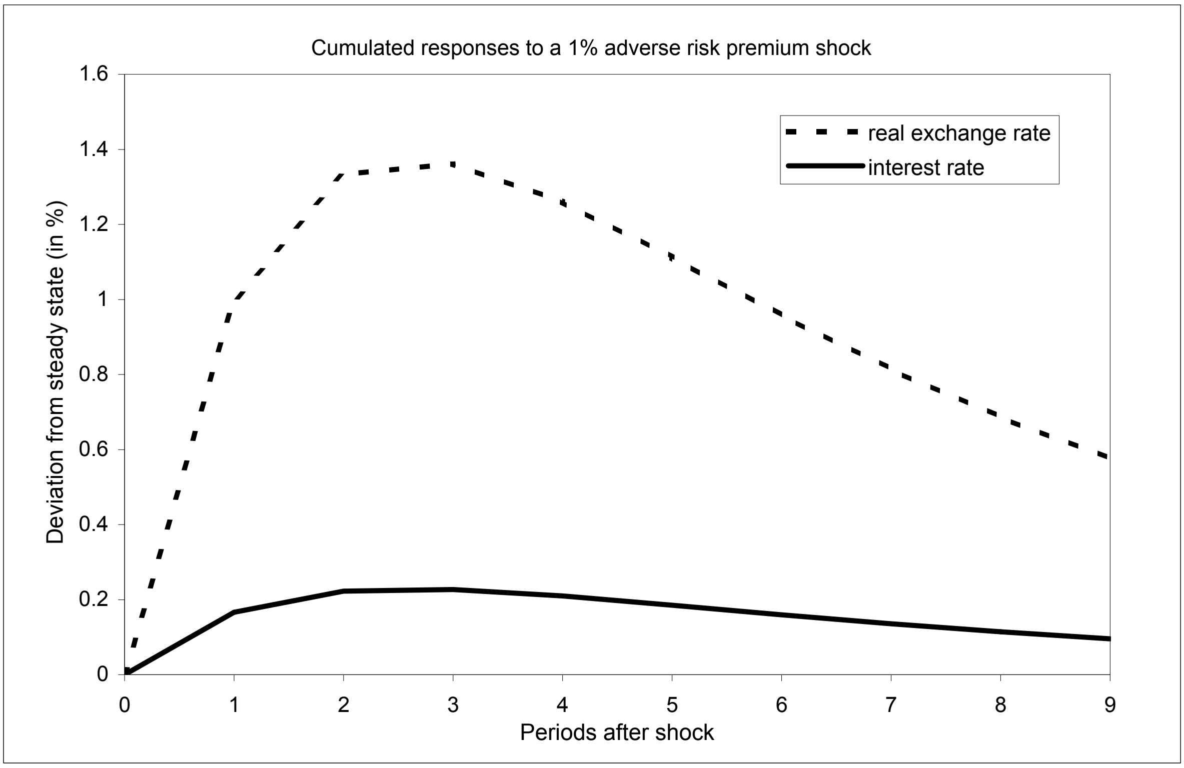


Figure 6. Imperfect information cases: Impulse responses of interest rate and real exchange rate (δ = -0.1)



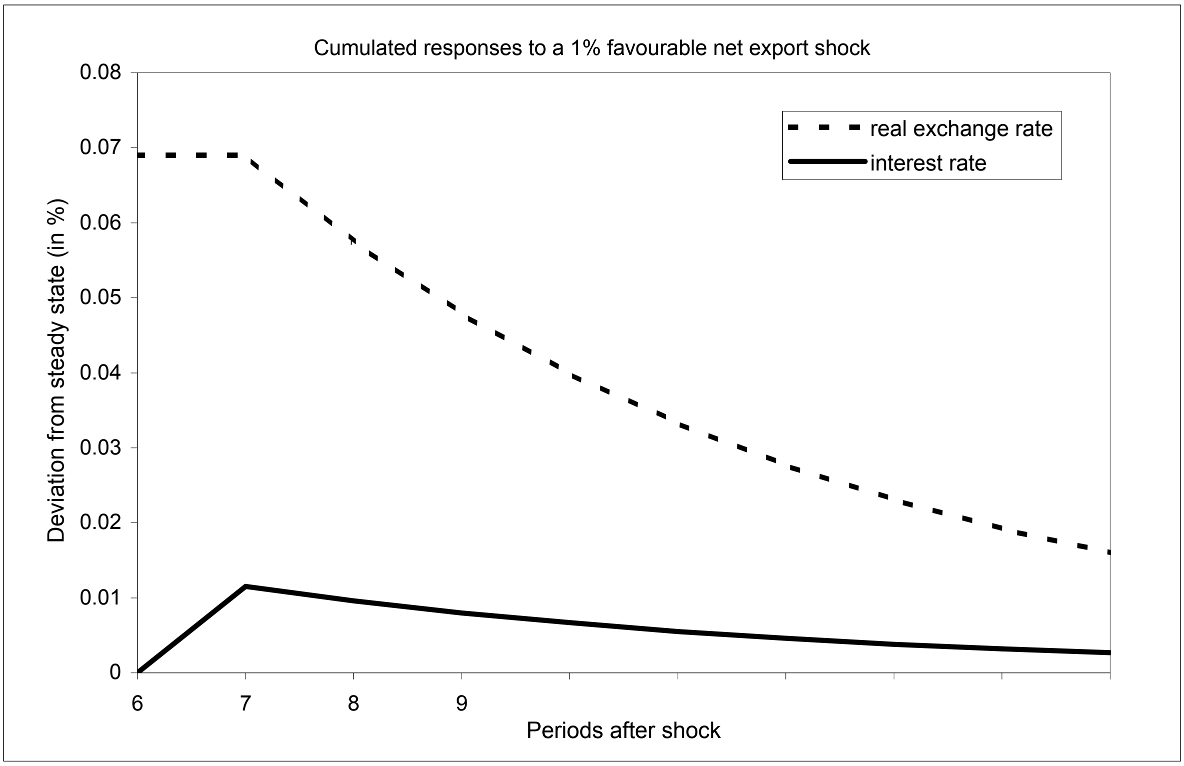
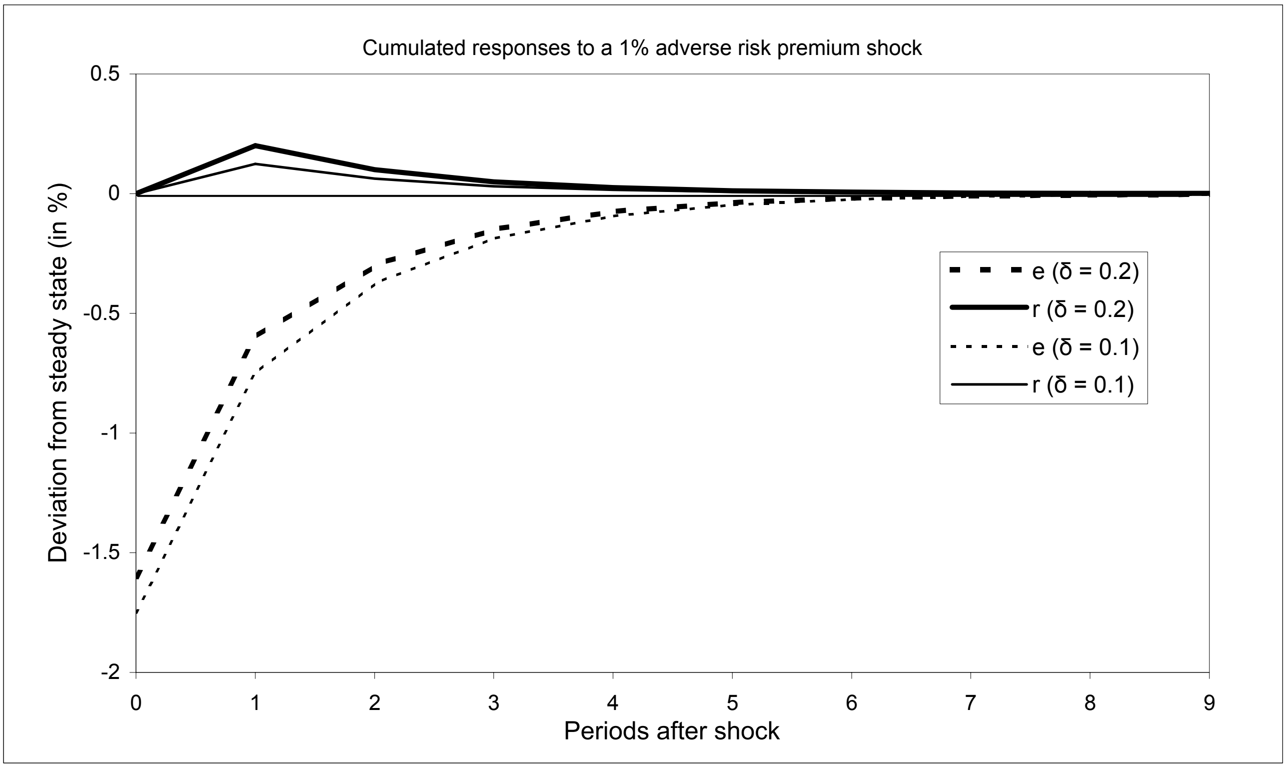


Figure 7. Asymmetric information without signal extraction: Impulse responses of interest rate and real exchange rate (δ > 0)



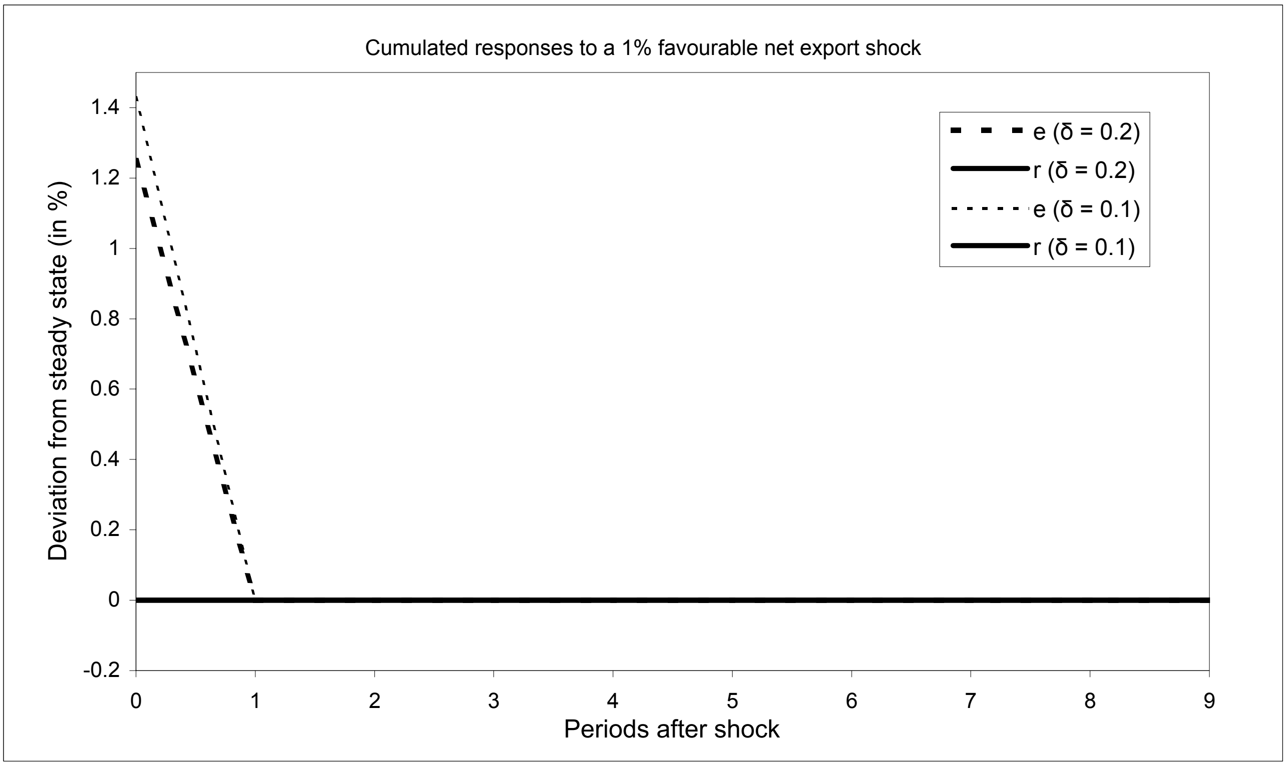


Figure 8. Asymmetric information without signal extraction: Impulse responses of interest rate and real exchange rate (δ = -1.5)