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HOW DOES INFORMATION AFFECT THE COMOVEMENT BETWEEN INTEREST RATES AND EXCHANGE RATES?

by Marcelo Sánchez

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In 2006 all ECB publications will feature a motif taken from the €5 banknote.

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2 Correspondence to: European Central Bank, Kaiserstrasse 29, D-60311 Frankfurt am Main, Germany. Tel: +49 69 1344 6531; fax: +49 69 1344 6353. E-mail address: marcelo.sanchez@ecb.int

Address
Kaiserstrasse 29
60311 Frankfurt am Main, Germany

Postal address
Postfach 16 03 19
60066 Frankfurt am Main, Germany

Telephone
+49 69 1344 0

Internet
http://www.ecb.int

Fax
+49 69 1344 6000

Telex
411 144 ecb d

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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. It also distinguishes between cases of expansionary and contractionary depreciations. Full information results are not robust to the presence of informational frictions. For economies exhibiting expansionary or strongly contractionary depreciations, such frictions lead to 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 authority does not react on impact to shocks. 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

JEL Classification: E52, E58, F31, F41

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 contractionary depreciations and - under forward-looking foreign exchange markets - also for mildly contractionary ones.

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 a stabilising 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 dampening 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 modelling 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 without 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 and are thus taken to play no informational role.[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 results that depend on which shocks are expected to be more likely to occur. 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 the usually assumed 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 are 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

[7] This empirical literature has been conducted mostly for advanced economies, including recent contributions by Kim (2003) and Sims and Zha (2006). 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).

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 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 stabilising 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.[8] 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

[8] For a more detailed description of the full information setup, see Sánchez (2005).

private sector:

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

$$y_t = -\beta r_t - \delta e_t + \varepsilon_t^D \tag{2}$$

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

$$r_t = R_t - E_t \pi_{t+1} \tag{4}$$

where all variables, except the interest rate, are in logarithms and expressed as deviations from steady state values. 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.

Aggregate supply schedule (1) links inflation (π_t) to the output gap (y_t) term and an exchange-rate pass through term. An increase in the real exchange rate (e_t) denotes an appreciation. Expression (2) states that aggregate demand is decreasing in the real interest rate (r_t). Output is also allowed to depend positively or negatively on the real exchange rate. Equation (3) is an uncovered interest parity condition, while (4) is the Fisher equation.

The central bank minimises an intertemporal loss function that penalises deviations of output from its potential level, $y_t - \varepsilon_t^S$, and deviations of inflation from the target (or objective), $\pi_t - \tilde{\pi}_t$:

$$E_t \sum_{i=0}^{\infty} \rho^i L_{i+1}$$

$$\text{where } L_t = \alpha^2(y_t - \varepsilon_t^S)^2 + \chi(\pi_t - \tilde{\pi}_t)^2 \tag{5}$$

To solve the model, I 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. Moreover, there is discretion on the part central bank and expectations are rational. As a result, I obtain $E_{t-1}\pi_t = E_{t-1}\tilde{\pi}_t$, that is, expected inflation equals expected targeted inflation. Using this, and assuming that the inflation target adopts a fixed and credible value of $\tilde{\pi}$, the optimal inflation rate, π_t^{opt}, is found to follow:

$$\pi_t^{opt} = \tilde{\pi} - (1-\varphi)\gamma(e_t - E_{t-1}e_t) \tag{6}$$

where $\varphi \equiv \chi/(1+\chi)$. 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.

Next, I assume that the risk premium shock, ε_t^f, and the excess demand shock, ε_t^{xd}, both 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 $\varepsilon_t^{xd} = \rho\varepsilon_{t-1}^{xd} + \eta_t^{xd}$ in the latter.[9] In consequence, I obtain:

$$e_t = (1-\omega)\, E_t e_{t+1} - \frac{\theta\varphi\gamma}{\alpha}(e_t - E_{t-1}e_t) + \theta\varepsilon_t^{xd} - (1-\omega)\,\varepsilon_t^f \tag{7}$$

Examination of (7) 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 (7) in the absence of bubbles can be expressed in terms of

[9] Composite shock ε_t^{xd} is defined to equal $\varepsilon_t^{xd} \equiv \varpi(\varepsilon_t^d - \varepsilon_t^S) + (1-\varpi)\varepsilon_t^x$, where ϖ denotes the share of aggregate demand in total output, and ε_t^d and ε_t^x are shocks to aggregate demand and net exports, respectively. Coefficient ρ equals zero in my analysis of a risk premium shock and ρ_x in the study of the net export shock. Similarly, ε_t^{xd} equals zero and $(1-\varpi)\eta_t^x$ for all t, respectively.

the real exchange rate and the real interest rate as:

$$e_t = \frac{1}{\beta(1-\rho)+\delta}\left[\varepsilon_t^{xd} - (1-\sigma)\eta_t^{xd}\right] - \frac{\beta}{\beta(1-\rho_f)+\delta}\left[\varepsilon_t^f - (1-\sigma)\xi_t\right] \quad (8)$$

$$r_t^{opt} = \frac{1}{\beta(1-\rho)+\delta}\left[(1-\rho)\varepsilon_t^{xd} - (1-\sigma)\eta_t^{xd}\right] + \frac{1}{\beta(1-\rho_f)+\delta}\left[\delta\varepsilon_t^f + \beta(1-\sigma)\xi_t\right] \quad (9)$$

where $\sigma \equiv \alpha/(\alpha+\theta\varphi\gamma)$. From (9), the central bank raises interest rates in response to a positive excess demand shock and an unfavourable risk premium shock.

I now turn to illustrating the properties of the model by means of simulations. I attach numerical values to the parameters, following calibrations used in previous work for small open economies. For key parameter δ, the baseline value is chosen to equal 0.2, as in Ball (1999). 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.[10] All other parameters are kept unchanged throughout the analysis. The values of α, β and γ are taken from Ball (1999) to equal 0.4, 0.6 and 0.2, respectively. In addition, 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 to 0.8 from 0.89, to capture the fact that many small open economies 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. 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).

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

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 $\delta < -2\beta$).[11] Panel A of 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 chart) and a one percent favourable net export shock (bottom chart). Panel B of Figure 1 reports the corresponding cumulated impulse responses for $\delta = -1.5$.

For an economy exhibiting conventional expansionary depreciations, Figure 1 (panel A, top chart) 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 as well as incipient favourable output effects. In view of the unambiguous inflationary pressures stemming from this shock (via both exchange rate pass-through and output), the monetary authority raises interest rates.

Figure 1 (panel A, bottom chart) shows that a favourable net export shock drives both the interest rate and real exchange rate up. The mix of monetary policy tightening and exchange rate appreciation in turn helps ease excess demand and inflationary pressures.

In panel A of 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

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

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.

Next, I study an economy exhibiting large contractionary depreciations ($\delta < -2\beta$). Panel B of Figure 1 (top chart) indicates that an adverse risk premium shock induces both a rise in interest rates and a real exchange rate depreciation. Unlike the case of a positive δ, the shock now induces an incipient contraction in aggregate demand via, say, balance sheet effects. Interest rates are hiked in the present case to a point where exchange rates end up stronger, thereby helping mitigate inflationary pressures and supporting the real side of the economy.

In panel B of Figure 1 (bottom chart) a favourable net export shock drives both interest rates and the real exchange rate down. The exchange rate depreciation reduces demand, thus partly offsetting the excess demand conditions in the goods market.

In sum, the present model allows us to reproduce all full information results emphasised in the literature. The covariance between exchange rates and interest rates, conditional on adverse risk premium, is negative for expansionary depreciations and positive for contractionary ones. Moreover, interest rates are predicted to eventually rise in response to an adverse net export shock in economies displaying strongly contractionary depreciations, and to be lowered in the case of expansionary depreciations. Under the latter, a smaller degree of responsiveness of aggregate demand to the exchange rate implies that adverse financial and real disturbances both induce a larger depreciation. In addition, a smaller - but still positive - δ makes the central bank hike interest rates further under a negative risk premium disturbance, and loosen by more in the case of an adverse net export shock.

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

The condition $\mid 1-\omega \mid > 1$ refers to mildly contractionary depreciations, that is, a range of $\delta \in (-2\beta, 0)$. In this case, the system is fundamentally backward looking, and the real exchange rate can be expressed as

$$\begin{aligned} e_t \quad = \quad & \left(\frac{1}{1-\omega}\right)^{\tau} e_{t-\tau} - \frac{1}{\beta}\sum_{s=1}^{\tau}\left(\frac{1}{1-\omega}\right)^{s-1} \varepsilon_{t-s}^{xd} + \sum_{s=1}^{\tau}\left(\frac{1}{1-\omega}\right)^{s-1} \varepsilon_{t-s}^{f} + \zeta_t \\ & + \sum_{s=1}^{\tau-1}\left(\frac{1}{1-\omega}\right)^{s-1}\left(\frac{1}{1-\omega} - \frac{\varphi\gamma}{\beta\alpha}\right)\zeta_{t-s} + \left(\frac{1}{1-\omega}\right)^{\tau-1}\frac{\varphi\gamma}{\beta\alpha}\zeta_{t-\tau} \qquad (10) \end{aligned}$$

where ζ_t is a sunspot defined by $e_t = E_{t-1}e_t + \zeta_t$. This variable is an error that is purely extrinsic to the economy. In the following, I neglect for simplicity sunspot ζ_t.

Use of (3) and (10), following the reasoning leading to expression (9) in the previous subsection, allows me to characterise the central bank's reaction function in terms of the real interest rate.

Panel C of Figure 1 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. Figure 1 (panel C, top chart) reports that an adverse risk premium shock leaves both the interest rate and real exchange rate unchanged on impact. As with the case of strongly contractionary depreciations, shock ε_t^f induces a rise in interest rates, eventually turning the real exchange rate stronger. This limits inflationary pressures and offsets contractionary forces in place.

In Figure 1 (panel C, bottom chart), a favourable net export shock raises the interest rate, leaving backward-looking real exchange rate unchanged on impact. 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.

Summarising, 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 coincides with that found for strongly contractionary depreciations, except that such positive correlation is now delayed to the second period onwards, with both the interest rate and real exchange rate being left unchanged on impact. Turning to the case of a favourable net export 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. One important difference emerges, however, with respect to the case of stongly contractionary depreciations. In the present case, the falls in real exchange rates and interest rates are delayed to the second period onwards, instead of taking place on impact. As analysed in this subsection, in the initial period interest rates are raised and the exchange rate remains at baseline.

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 at the time monetary policy decisions are taken, and second, shocks are assumed not to be known to any agent in the model at that time. 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 second 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".

Given the large number of cases considered in this paper (four values for δ, two shocks and three different informational assumptions), subsection 3.1 starts by previewing the comparison of results across models for one concrete example. This is the case of an economy exhibiting expansionary depreciations and being hit by a favourable net export shock. Subsections 3.2 and 3.3 then describe the two imperfect information models in turn. Subsection 3.4 compares the full set of results obtained from these two approaches with those of full information.

3.1 An illustrative example

Let us first discuss the implications of asymmetric information for an economy in which depreciations are expansionary and that faces a favourable net export disturbance. As we have seen, under full information such shock induces an interest rate hike and real exchange rate appreciation. This outcome in turn contributes to offsetting excess demand and inflation created by the shock. Under asymmetric information with signal extraction, the response of the policymaker will depend on the relative variance of disturbances. I will later assume, in line with the literature, that risk premium shocks exhibit the largest variability of the two shocks considered. Under that assumption, the reactions of endogenous variables following a favourable real shock is largely interpreted by the central bank to result from an exogenous reduction in risk premia instead. Therefore, a positive disturbance to net exports leads to a fall in both interest rates and the real exchange rate. This result is exactly the opposite of that obtained under full information.

The comparison between full information and asymmetric information without signal extraction in the present case follows a different pattern. Under the latter type of informational frictions, the central bank lacks contemporaneous information about output and prices, and thus leaves interest rates unchanged at the time the real shock hits - as opposed to hiking them under full information. Regarding the real exchange rate, the appreciation following the disturbance mirrors that found under full information.

The example examined here reveals that informational assumptions do matter for the comovements between interest rates and exchange rates. Moreover, asymmetric information appears to have different implications depending on whether the monetary authority is able to extract some news from the private sector or not. I will come back to similar comparisons in subsection 3.4, where I contrast the full set of results.

3.2 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.[12] 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 assumptions about information, I rewrite equations (1), (2) and (3) as

$$
\begin{aligned}
\pi_t &= E_{t-1}\pi_t + \alpha'\left(y_t - \varepsilon_t^S\right) - \gamma'(s_t - E_{t-1}^+ s_t) && (11)\\
y_t &= -\beta r_t - \delta(s_t + p_t) + \varepsilon_t^D && (12)\\
R_t &= -E_t^+ s_{t+1} + s_t + \varepsilon_t^f && (13)
\end{aligned}
$$

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 2 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), (11), (12) and (13). The central bank's contemporaneous inflation perception error is

$$\eta_t \equiv \pi_t - E_t\pi_t = \frac{\alpha'}{1+\alpha'\delta}\left(\eta_t^{xd} - E_t\eta_t^{xd}\right) \quad (14)$$

The central bank's optimisation, imposing rational expectations and assuming a fixed and credible inflation target, implies $E_{t-1}\pi_t = \tilde{\pi}$. 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 (11) and (12), 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

[12] 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.

the stochastic processes driving the shocks to the economy as in section 2. Moreover, I postulate that the signal extraction function is of the form

$$E_t \eta_t^{xd} = \lambda \left[s_t - s_t^* \right] \tag{15}$$

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 (15) 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.[13] In (15), 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

$$R_t = \tilde{\pi} + s_t + p_t + \frac{\beta+\delta}{\beta(1-\rho_f)+\delta} \rho_f \varepsilon_t^f - \frac{\rho}{\beta(1-\rho)+\delta} \varepsilon_t^{xd} \tag{16}$$

$$s_t = -\tilde{\pi} - p_{t-1} - \frac{\beta}{\beta(1-\rho_f)+\delta} \rho_f \varepsilon_t^f + s_1 \xi_t + \frac{1}{\beta(1-\rho)+\delta} \varepsilon_t^{xd} + s_2 \eta_t^{xd} \tag{17}$$

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

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

[13] 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.

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

Moreover, equilibrium inflation and output levels are

$$\pi_t = \tilde{\pi} - (1-\varphi)\gamma'(s_t - E^{+}_{t-1}s_t) + \eta_t \tag{18}$$
$$y_t = \varepsilon^S_t + \frac{\varphi\gamma'}{\alpha'}(s_t - E^{+}_{t-1}s_t) + \frac{1}{\alpha'}\eta_t \tag{19}$$

The final step is to determine λ from

$$\lambda = \frac{Cov\left(\eta^{xd}_t, s_t - s^*_t\right)}{Var\left(s_t - s^*_t\right)} \tag{20}$$

Using (15), (20) and the definition of s^*_t above, λ can be found to equal

$$\lambda = \frac{\left(s_2 + \frac{1}{\beta(1-\rho)+\delta}\right) Var(\eta^{xd})}{\left(s_1 - \frac{\beta}{\beta(1-\rho_f)+\delta}\right)^2 Var(\xi) + \left(s_2 + \frac{1}{\beta(1-\rho)+\delta}\right)^2 Var(\eta^{xd})} \tag{21}$$

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:

$$\begin{aligned} s_t &= \left(\frac{\beta+\delta}{\beta}\right)^{\tau} s_{t-\tau} + \left(\frac{\beta-\delta}{\delta}\right)\left[1-\left(\frac{\beta+\delta}{\beta}\right)^{\tau}\right]\tilde{\pi} + \frac{\delta}{\beta}\sum_{l=1}^{\tau}\left(\frac{\beta+\delta}{\beta}\right)^{l-1} p_{t-l-1} \\ &\quad -\frac{\rho}{\beta}\sum_{l=1}^{\tau}\left(\frac{\beta+\delta}{\beta}\right)^{l-1}\varepsilon_{t-l-1}^{xd} + \sum_{l=1}^{\tau}\left(\frac{\beta+\delta}{\beta}\right)^{l-1}\varepsilon_{t-l}^{f} \end{aligned} \tag{22}$$

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 (22) and the corresponding expression under full information, that is (10), 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 (10) and (22) also have in common the implication that the real exchange rate eventually returns to steady state. The latter results is easy to see in (10) because this expression is directly written in terms of the real exchange rate e_t. But it also holds in (22). 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.

3.3 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 i) information still becomes available to foreign exchange market participants before it is known to the central bank; but ii) it is not available to any agent in the economy at the time of the monetary policy decision. Item ii) means that, initially, 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 after the central bank forms expectations and takes its decision. The current exchange rate is, like output and prices, unknown to the central bank when setting interest rates.[14] 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 3.1, nominal exchange rates are to be explicitly handled in order to solve the model. The model still consists of equations (4), (5), (11), (12) and (13). However, the solution needs to incorporate the specific timing of information described in the

[14] 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.

previous paragraph. In particular, the nominal exchange rate s_t needs to be replaced by $E_t s_t$ when it comes to modelling the central bank's expectations 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

$$\eta_t \equiv \pi_t - E_t\pi_t = \frac{1}{1+\alpha'\delta}\left[\alpha'\eta_t^{xd} - (\alpha'\delta + \gamma')(s_t - E_t s_t)\right] \tag{23}$$

Once more, we have $E_{t-1}\pi_t = \tilde{\pi}$, and, using (4), $r_t = R_t - \tilde{\pi}$.

The equilibrium inflation and output levels equal

$$\pi_t = \tilde{\pi} + \eta_t \tag{24}$$

$$y_t = \varepsilon_t^S + \frac{\gamma'}{\alpha'}(s_t - E_{t-1}^{+} s_t) + \frac{1}{\alpha'}\eta \tag{25}$$

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), (11), (12), (13), (23) and (24), the equilibrium nominal exchange rate can then be found to equal

$$s_t = E_{t-1}^{+} s_t - \varepsilon_t^f + \frac{1}{\beta}\left[(\beta - \delta)\,\tilde{\pi} - \delta p_{t-1} + +\rho\varepsilon_{t-1}^{xd} - \delta E_t s_t\right] \tag{26}$$

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

$$R_t = \tilde{\pi} + \frac{\delta}{\beta(1-\rho_f)+\delta}\rho_f\varepsilon^f_{t-1} + \frac{1-\rho}{\beta(1-\rho)+\delta}\rho\varepsilon^{xd}_{t-1} \tag{27}$$

$$s_t = -\tilde{\pi} - p_{t-1} - \frac{\beta}{\beta(1-\rho_f)+\delta}\varepsilon^f_t + s_3\xi_t + \frac{\rho}{\beta(1-\rho)+\delta}\varepsilon^{xd}_{t-1} + s_4\eta^{xd}_t \tag{28}$$

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 (22). 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 (24), while equilibrium output simplifies further from (25) to $y_t = \varepsilon^S_t + \eta_t/\alpha'$.

3.4 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 Figure 1 (the full information case) to Figures 2 (asymmetric information with signal extraction) on the one hand, and 3 (asymmetric information without signal extraction) on the other. In addition to the parameter values used for calibration in section 3, simulation analysis under asymmetric information with signal extraction 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 $Var(\varepsilon^x) = 0$.

Let us start by comparing the full information case with that of asymmetric information with signal extraction. Under the latter assumption, panel A of Figure 2 shows, for the two alternative positive values of δ, the cumulated impulse responses to risk premium and net export shocks, which can be compared with the corresponding panel of Figure 1 under full information. Panels B and C of Figure 2 report cumulated impulse responses for $\delta = -1.5$ and $\delta = -0.1$, thereby being comparable to the respective panels of Figure 1.

In the case of an economy exhibiting standard expansionary depreciations, panel A of Figure 2 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, panel A) depending on which of the two shocks are realised. In Figure 2 (panel A, top chart), 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, the bottom chart of Figure 2 (panel A) stands in sharp contrast with the corresponding chart in Figure 1. In the latter chart, which obtains under full information, the disturbance induces rises in both interest rates and the real value of domestic currency. In Figure 2 (panel A), 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. As discussed in subsection 3.1, 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.[15]

I now examine the role of the responsiveness of output to the exchange rate. Panels A in Figures 1 and 2 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 net export disturbances.[16] It is worth looking at this conclusion regarding the

[15] 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.

[16] One interesting difference between the bottom charts in panels A of Figures 1 and 2

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.

Turning to the case of strongly contractionary depreciations, how much results are affected by informational frictions once more depends on which of the two disturbances hit the economy (panel B in Figure 2 *versus* that in Figure 1). Under full information, panel B of Figure 2 (top chart) 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 2 (panel B, bottom chart) shows that a favourable net export shock drives both interest rates and the real exchange rate up, as opposed to down in the corresponding chart in Figure 1. The reason for this difference lies, as discussed for Figure 2 (panel A, bottom chart), 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 panel C of Figure 2 with that of Figure 1 permits us to assess whether results under asymmetric information with signal extraction differ from those obtained under full information. It is worth pointing out that this comparison carries out to both types of asymmetric information, and not simply to that with signal extraction. To start with, the reason why results for the two imperfect information models coincide here is better understood in two steps. First, in neither case does the central bank observe the shocks presently hitting the economy. Second, in

is that the interest rate and the exchange rate (in deviations from steady state) are now identical. This can be corroborated in equation (16) by setting the risk premium shock to zero and, in line with my calibrations, ρ_x and thus ρ to zero as well.

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 panels C of Figures 1 through 3 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 charts in panels C of Figures 1 through 2 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 chart in panel C of Figure 1 is different from the corresponding charts in Figures 2 and 3, 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.[17]

We have seen that panels C of Figures 2 and 3 report 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 panels A and B of Figure 3.

I now turn to the comparison between full information and the other type of informational imperfections, that of asymmetric information without signal extraction. For the latter case, panel A of Figure 3 (top chart) shows impulse responses for an economy displaying expansionary depreciations to an adverse risk premium shock. The main pattern here is that the interest rate rises and the exchange rate depreciates, qualitatively the same results as obtained under full information (Figure 1, panel A, top chart).[18] 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

[17] 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.

[18] For this same shock, the similarity of results carries over to the case of asymmetric information with signal extraction (Figure 2, panel A, top chart).

bottom chart in panel A of Figure 3 indicates that, in the face of a net export shock, the 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, while changing δ affects the intensity with which the central bank responds to shocks, it 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 panel A of Figure 3 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, panel B of Figure 3 presents in its top chart 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 1, panel B).[19] As with panel A of Figure 3 (top chart), 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 chart in panel A of Figure 3 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,

[19] Once more, for this same disturbance, results are equally comparable to those found under asymmetric information with signal extraction (Figure 2, panel B).

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 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 stabilising 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). 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 under mildly contractionary depreciations, even after relaxing the assumption of full information. While in my study sunspots are 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.

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A) Case δ > 0 | B) Case δ = -1.5 | C) Case δ = -0.1

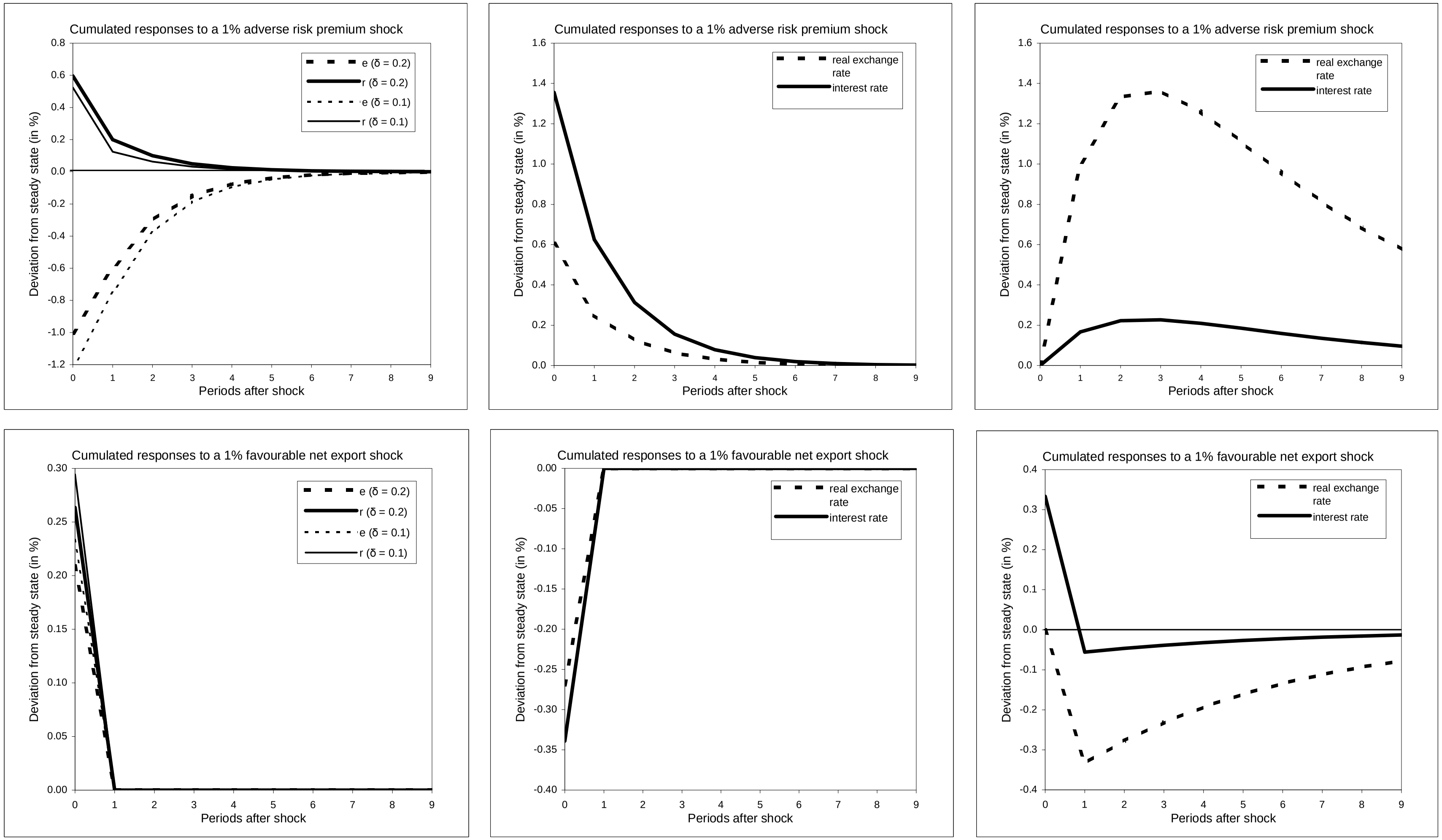

Figure. 1. Full information case: Impulse responses of interest rate and real exchange rate

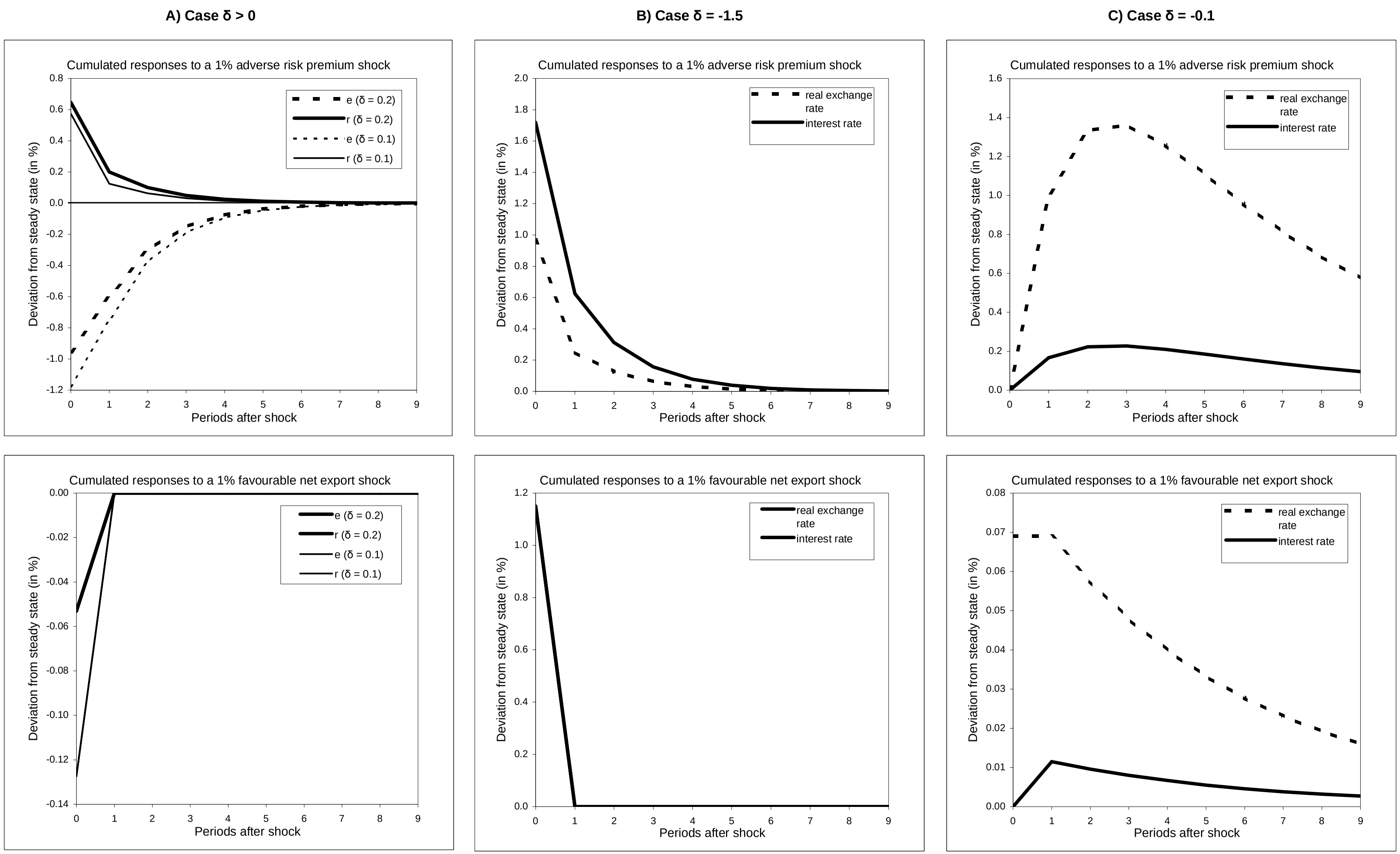

Figure. 2. Asymmetric information with signal extraction: Impulse responses of interest rate and real exchange rate

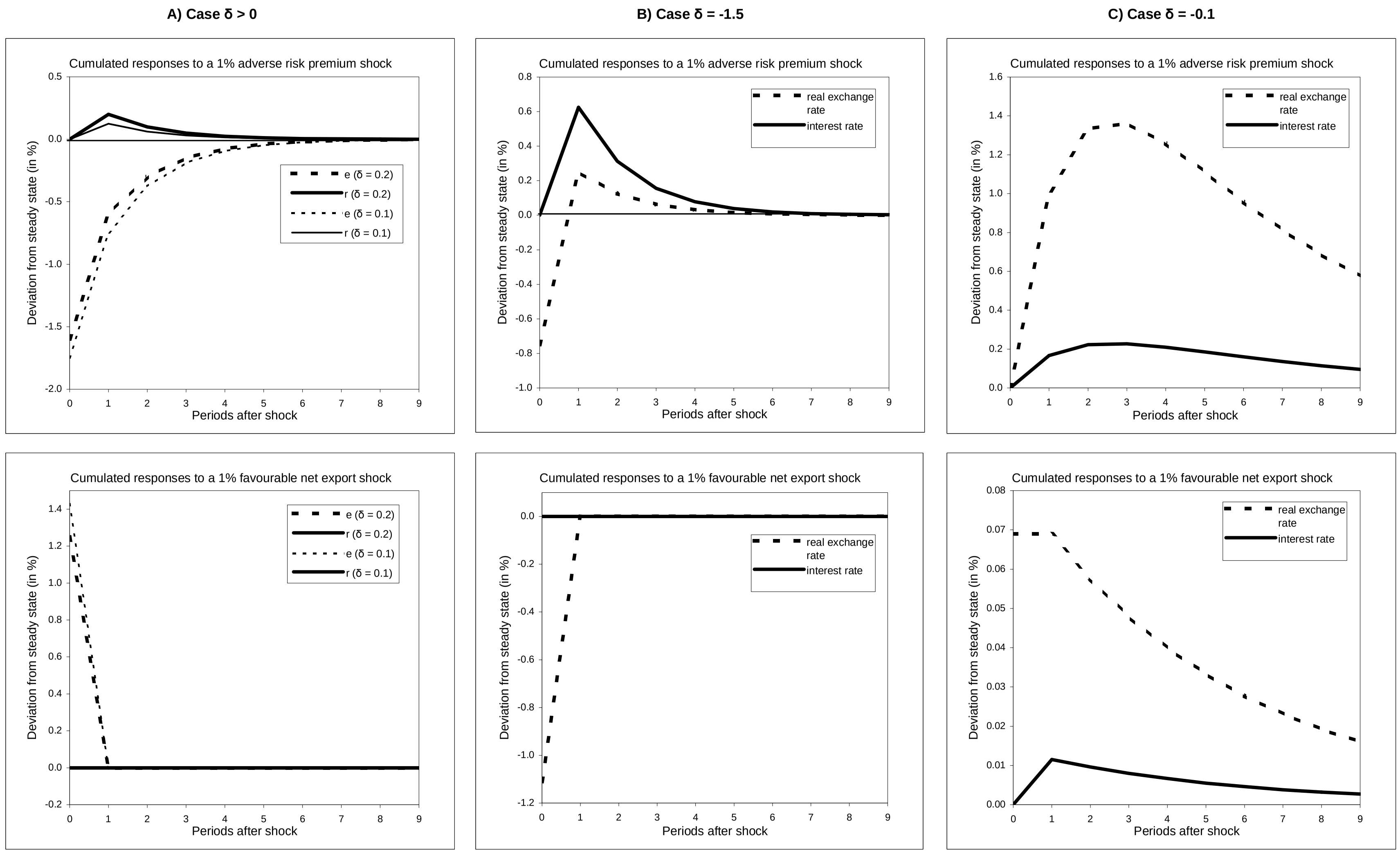

Figure. 3. Asymmetric information without signal extraction: Impulse responses of interest rate and real exchange rate

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