How much you know matters: A note on the exchange rate disconnect puzzle

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HOW MUCH YOU KNOW MATTERS: A NOTE ON THE EXCHANGE RATE DISCONNECT PUZZLE

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Abstract

This paper offers a dynamic model of the foreign exchange market where some investors in the market are more informed than others. By adjusting the proportion of informed investors in the market, it is shown that the disconnect between macroeconomic variables and the exchange rate is sensitive to the amount of asymmetric information in the market. A surprising finding is that this disconnect is bigger when the proportion of informed investors in the market is smaller.

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KEY WORDS: Market Microstructure; Foreign Exchange Market; Asymmetric Information

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1 Introduction

The disconnect between macroeconomic fundamentals and the exchange rate has been well-established in the exchange rate literature. A notable demonstration of this disconnect by Flood and Rose (1995) shows that volatility of variables such as money and output does not appear to be significantly different during regimes of fixed and floating exchange rates. A theoretical explanation for this disconnect has been offered by Bacchetta and van Wincoop (2006) and they demonstrate how information dispersion can cause rational confusion among investors, which then magnifies the disconnect between macroeconomic fundamentals and the exchange rate.

In this short paper, I build upon the explanation by Bacchetta and van Wincoop (2006) and show that the disconnect between macroeconomic variables and the exchange rate is sensitive to the amount of asymmetric information in the market. By controlling the proportion of investors who receive noisy private signals about future macroeconomic fundamentals on top of the public signals that all investors receive, I can adjust the level of information dispersion in the model. This additional control allows me to demonstrate that the response, as well as persistence, of equilibrium exchange rate to fundamental and non-fundamental shocks is quite different for varying levels of asymmetric information in the market. The findings also suggest that strengthening the connection between macroeconomic fundamentals and the exchange rate might be possible by increasing the proportion of investors holding more information in the market.

Recently, with the availability of customer order flow data, many researchers have shown that the impact of order flow on the equilibrium exchange rate depends on the type of customers initiating the order[1]. These findings, coupled with the finding that dealers offer smaller spreads to informed customers as shown in Osler, et al. (2010), suggest that differing levels of impact of customer orders on the equilibrium exchange rate might be due to different levels of information they possess. This empirical finding is represented in the model of this paper through 1) the noisy public signal every investor receives and 2) the noisy private signal only a proportion of investors receive. The idea to control for the proportion of investors receiving the private signal

[1] Marsh and O'Rourke (2005), Bjonnes, et al. (2004, 2005), Onur (2008) and Fan and Lyons (2003) are only a few. See Evans and Rime (2010) for a more detailed list of empirical papers in the field.

is motivated by an interesting paper by Marsh and O'Rourke (2005), where for different currency pairs, they measure the probability of a dealer trading with an informed investor who might have more information about the future of the exchange rate than dealers do. Authors offer a measure called PIN (probability of informed trading) for six different currency pairs and for four different customer categories and find that the probability of a dealer trading with an informed investor can be as low as 10 percent for certain currency and customer groups, whereas as high as over 60 percent for others. Even within the same customer groups, they report a gap of almost 20 percentage points from one currency pair to another. These findings are good indication that a theoretical model that allows for varying levels of asymmetric information in the market is needed in the literature. In that regard, I extend the theoretical model by Onur (2008) into a dynamic setting a la Bacchetta and Van Wincoop (2006) to provide this needed theoretical model.

The rest of the paper is arranged as follows. Section 2 lays out the basic model. Section 3 outlines the solution to the model. Section 4 offers results and analysis and section 5 concludes.

2 Theoretical Model

The setup of the model follows from Onur (2008). It is a two-country monetary model of exchange rate determination with money market equilibrium, purchasing power parity and interest rate parity assumed.

There is a continuum of investors in both countries and they are distributed on the $[0, 1]$ interval. I assume a myopic agent setup where agents live for two periods and make only one investment decision. Investors are identical in the sense that they have the same utility function and they know that exchange rate depends on the expectations of future fundamentals. Investors in both countries can invest in money of their own country, bonds of the home country for a return of i_t, bonds of the foreign country for a return of i_t^*, and in some type of production with a fixed return. This production is assumed to depend on the exchange rate as well as on real money holdings of investor i, μ_t^i. Thus, the production function is written as $f\left(\mu_t^i\right) = \kappa_t^i s_{t+1} - \mu_t^i \left(\ln\left(\mu_t^i\right) - 1\right)/\alpha$, for $\alpha > 0$. The coefficient κ_t^i is the exchange rate exposure variable.

Investor i will want to hedge himself, and this hedge against non-asset income will add to the demand in the foreign exchange market. An investor's hedge demand changes every period and it is known by the investor himself only.

Investor i maximizes his expected discounted future utility conditional on information known at t, F_t^i, and his budget constraint. The maximization problem can be written as

$$\begin{aligned} \max \quad & -E_t\left[e^{-\gamma c_{t+1}^i} | F_t^i\right] \\ \text{subject to } c_{t+1}^i \quad = \quad & (1+i_t)w_t^i + (s_{t+1} - s_t + i_t^* - i_t)B_t^i - i_t\mu_t^i + f\left(\mu_t^i\right), \end{aligned} \tag{1}$$

where w_t^i is wealth at the start of period t, B_t^i is the amount invested in foreign bonds, and $s_{t+1} - s_t + i_t^* - i_t$ is the log-linearized excess return on investing in foreign bonds. Investor i chooses the optimal amount of foreign bonds to hold and the first order condition becomes

$$s_t = E^i(s_{t+1}) - i_t + i_t^* - \gamma\sigma_{t,i}^2\left(B_t^i + b_t^i\right), \tag{2}$$

where $\sigma_{t,i}^2 = var(s_{t+1})$ is the conditional variance of next period's exchange rate and b_t^i is the hedge demand due to the exchange rate exposure of non-asset income, $b_t^i = \kappa_t^i$. I write the interest differential in terms of the exchange rate and fundamentals to obtain $i_t - i_t^* = \frac{1}{\alpha}(s_t - f_t)$, where the fundamentals are defined as $f_t = (m_t - m_t^*)$[2].

Investor i's foreign bond demand can be written as

$$B_t^i = \frac{E^i(s_{t+1}) - s_t + i_t^* - i_t}{\gamma\sigma_{t,i}^2} - b_t^i, \tag{3}$$

Hedging demand emerging from the exchange rate exposure variable is assumed to be composed of an average term and an idiosyncratic term, $b_t^i = b_t + \varepsilon_t^i$. The average hedging demand is unobservable to any of the investors but they know the autoregressive process it follows, $b_t = \rho_b b_{t-1} + \varepsilon_t^b$, where $\varepsilon_t^b \sim N(0, \sigma_b^2)$.

Applying this market equilibrium condition to (3) yields

[2]Note that m_t and i_t are logs of money supply and interest rate respectively.

$$\overline{E}_t(s_{t+1}) - s_t = i_t - i_t^* + \gamma b_t \sigma_t^2, \tag{4}$$

where $\overline{E}_t$ is the average expectation across all investors. Using equation (4) and the definition of fundamentals, the equilibrium exchange rate is given by

$$s_t = \sum_{k=0}^{\infty} \left(\frac{\alpha}{1+\alpha} \right)^k \overline{E}_t^k \left(f_{t+k} - \alpha\gamma\sigma_{t+k}^2 b_{t+k} \right), \tag{5}$$

where $\overline{E}_t^k$ are expectations of order $k > 1$, defined as $\overline{E}_t^k(s_{t+k}) = \int_0^1 E_t^i \left(\overline{E}_t^{k-1} (s_{t+k-1}) \right) di$ with $\overline{E}_t^1(s_{t+1}) = \overline{E}_t(s_{t+1})$ and $\overline{E}_t^0(s_t) = s_t$.

2.1 Information Structure

As well as observing all past and current values of fundamentals, investors also observe signals regarding future fundamentals. All investors in the market receive a noisy public signal about the future value of fundamentals. Asymmetric information arises from the fact that a proportion of investors also receive a noisy private signal about the future value of fundamentals in addition to the public signal received by every investor. I use ω to denote the proportion of investors who receive just the public signal. Throughout the paper, I choose to call them "uninformed" investors for tractability reasons. The remaining proportion of investors, $1 - \omega$, are classified as "informed" investors. Note that changing the ratio of informed investors to uninformed investors in the economy is equivalent to choosing how much private information exists in the market[3].

I Assume that the fundamentals in the economy are governed by the process

$$f_t = D(L)\varepsilon_t^f, \qquad \varepsilon_t^f \sim N(0, \sigma_f^2), \tag{6}$$

where $D(L) = d_1 + d_2 L + d_3 L^2 + ...$

I also assume the noisy public signal received by all investors to be denoted by z_t and the noisy private signal received by informed investor i to be denoted by ν_t^i. These signals carry

[3] When $\omega = 1$, every investor in the economy is receiving *only* the public signal so all are uninformed, and when $\omega = 0$, every investors is receiving *both* of the signals so all of them are informed.

information about the value of the fundamental T periods ahead, f_{t+T}. In the economy, let the noisy public signal be structured in the following manner:

$$\begin{aligned} z_t &= f_{t+T} + w_t^z \qquad where \\ w_t^z &= \rho_z w_{t-1}^z + \varepsilon_t^z \qquad \varepsilon_t^z \sim N(0, \sigma_z^2) \end{aligned} \tag{7}$$

The public signal is composed of two components, the actual value of future fundamentals and a persistent term, w_t^z. I assume that this persistent term follows an autoregressive process with $\rho_z < 1$.[4] The error term, ε_t^z, is independent from the value of future fundamentals and it is unknown to investors at time t. In this setup, public signal does not reveal the exact value of future fundamentals to the investors. On the other hand, the structure of the noisy private signal is:

$$\nu_t^i = f_{t+T} + \varepsilon_t^{\nu i} \qquad \varepsilon_t^{\nu i} \sim N(0, \sigma_\nu^2), \tag{8}$$

where error term of the signal being independent from u_t and other investors' signals. Due to the law of large numbers, I assume the average signal received by informed investors to be u_t, namely $\int_{1-\omega}^{1} \nu_t^i di = u_t$.

2.2 The Equilibrium Exchange Rate

I adopt a solution method suggested by Townsend (1983) and successfully applied to an exchange rate model by Bacchetta and Van Wincoop (2006). The solution method realizes that the equilibrium exchange rate and its components can be represented by a combination of current and past shocks to the economy. Realizing that $f_t = D(L)\varepsilon_t^f$ and $b_t = G(L)\varepsilon_t^b$; where $D(L) = d_1 + d_2 L + d_3 L^2 ...$ and $G(L) = 1 + \rho_b L + \rho_b^2 L^2 + ...$ where L is the lag operator, equation (5) can be represented in terms of current and past innovations. The next step is to conjecture a representation for the equilibrium exchange rate in terms of current and past innovations and

[4] The fact that z_t has a persistent term permits the public signal to be written in terms of its current and past innovations when conjecturing the equilibrium exchange rate.

then use the method of undetermined coefficients solution technique to solve for the equilibrium values of the coefficients. The conjectured exchange rate depends on shocks to observable and unobservable fundamentals:

$$s_t = A(L)\varepsilon_{t+T}^f + B(L)\varepsilon_t^b + C(L)\varepsilon_t^z \tag{9}$$

where $A(L)$, $B(L)$, and $C(L)$ are infinite order polynomials in L. Only a portion of these innovations are unknown to the investor. At time t, investors observe today's fundamentals as well as innovations from previous periods. That means values of ε^f between $t+1$ and $t+T$ are unknown to the investor. Investors also do not observe the non-fundamental shocks, ε^b, between t and $t-T$, as well as the public information shocks, ε^z, between t and $t-T$. Non-fundamental and public shocks before time $t-T$ are known by the investors.

Detailed solution of method of undetermined coefficients involves using equation (9) and the distinct information structure of two types of investors in the market to compute $\overline{E}_t\left(s_{t+1}\right)$ and σ_t^2. Once they are written in terms of innovations, I match their coefficients with the initial conjecture to find the equilibrium exchange rate. Note that both of the terms $\overline{E}_t\left(s_{t+1}\right)$ and σ_t^2 depend on the amount of asymmetric information in the market, ω.

3 SOLUTION TO THE MODEL

This section outlines the solution to the model. Note that in the model, the equilibrium exchange rate depends on the true value of future fundamentals T periods ahead. Accordingly, today's signals reveal the true value of fundamentals and non-fundamentals from T periods ago. As a result, expectations of future fundamentals at time t are affected by signals from previous periods.

In the conjectured exchange rate in equation (9), the exchange rate is written in terms of observed and unobserved innovations. Using the conjectured exchange rate, first $\overline{E}_t\left(s_{t+1}\right)$ and σ^2 are written in the same manner. Following equation (9), s_{t+1} is represented as $s_{t+1} = A(L)\varepsilon_{t+T+1}^f + B(L)\varepsilon_{t+1}^b + C(L)\varepsilon_{t+1}^z$ and following Bacchetta and Van Wincoop (2006) closely, the same equality can be re-written as:

$$
\begin{aligned}
s_{t+1} &= \underbrace{a_1\varepsilon^f_{t+T+1} + b_1\varepsilon^b_{t+1} + c_1\varepsilon^z_{t+1} + \Theta'\xi_t}_{unobservables} \\
&\quad + \underbrace{A^*(L)\,\varepsilon^f_t + B^*(L)\,\varepsilon^b_{t-T} + C^*(L)\,\varepsilon^z_{t-T}}_{observables} \qquad (10)
\end{aligned}
$$

where $\xi'_t = \left(\varepsilon^f_{t+T}, ..., \varepsilon^f_{t+1}, \varepsilon^b_t, ..., \varepsilon^b_{t-T+1}, \varepsilon^z_t, ..., \varepsilon^z_{t-T+1}\right)$ denotes the vector of unobservables and $\Theta' = (a_2, a_3, ..., a_{T+1}, b_2, b_3, ..., b_{T+1}, c_2, c_3, ..., c_{T+1})$ is the vector of coefficients matching those unobservables. The polynomials corresponding to the observables part of equation (10) are represented as:

$A^*(L) = (a_{T+2} + a_{T+3}L + ...)$

$B^*(L) = (b_{T+2} + b_{T+3}L + ...)$

$C^*(L) = (c_{T+2} + c_{T+3}L + ...)$

Thus, the expected value of tomorrow's exchange rate is written as:

$$
E^i_t(s_{t+1}) = \Theta' E^i_t(\xi_t) + A^*(L)\,\varepsilon^f_t + B^*(L)\,\varepsilon^b_{t-T} + C^*(L)\,\varepsilon^z_{t-T} \qquad (11)
$$

and

$$
\sigma^2 = var(s_{t+1}) = a_1^2\sigma_f^2 + b_1^2\sigma_b^2 + c_1^2\sigma_z^2 + \Theta' var(\xi_t)\,\Theta \qquad (12)
$$

The next step is to estimate $E^i_t(\xi_t)$ and $var(\xi_t)$ as functions of past innovations for the two different kinds of investors in the market.

3.1 Conditional Expectations for Informed Investors

The first step is to create a new vector of observables that carry only the information that is new to the investor. I subtract the known components from the observables s_t, υ^i_t, and z_t to define new variables s^*_t, ν^{i*}_t, and z^*_t. The vector of these unknown variables would be $Y^i_t = \left(s^*_t, s^*_{t-1}, ..., s^*_{t-T+1}, \nu^{i*}_t, \nu^{i*}_{t-1}, ..., \nu^{i*}_{t-T+1}, z^*_t, z^*_{t-1}, ..., z^*_{t-T+1}\right)$. Y^i_t vector provides information on the vector of unobservables ξ_t. Realizing that

$s_t^* = a_1\varepsilon_{t+T}^f + a_2\varepsilon_{t+T-1}^f + ... + a_T\varepsilon_{t+1}^f + b_1\varepsilon_t^b + b_2\varepsilon_{t-1}^b + ... + b_T\varepsilon_{t-T}^b + c_1\varepsilon_t^z + c_2\varepsilon_{t-1}^z + ... + c_T\varepsilon_{t-T}^z$
$\nu_t^{i*} = d_1\varepsilon_{t+T}^f + d_2\varepsilon_{t+T-1}^f + ... + d_T\varepsilon_{t+1}^f + \varepsilon_t^{\nu i}$ and
$z_t^* = d_1\varepsilon_{t+T}^f + d_2\varepsilon_{t+T-1}^f + ... + d_T\varepsilon_{t+1}^f + \varepsilon_t^z + \rho_z\varepsilon_{t-1}^z + \rho_z^2\varepsilon_{t-2}^z + ...$
everything can be represented in a more compact format:

$$Y_t^i = H'\xi_t + w_t^i \tag{13}$$

where $w_t^i = \left(0, ..., 0, \varepsilon_t^{\nu i}, ..., \varepsilon_{t-T+1}^{\nu i}, 0, ..., 0\right)'$.

Realize that the unconditional means of ξ_t and w_t^i are zero and let their unconditional variances be $\widetilde{P}$ and R respectively[5].

Following Townsend (1983), the conditional expectation can be written as:

$$\begin{aligned} E_t^i(\xi_t) &= MY_t^i \\ \text{where } M &= \widetilde{P}H\left[H'\widetilde{P}H + R\right]^{-1} \end{aligned} \tag{14}$$

and the conditional variance of ξ_t, $P \equiv var(\xi_t)$, is given by $P = \widetilde{P} - MH'\widetilde{P}$.

3.2 Conditional Expectations for Less-informed Investors

Following the same steps, first I define the new information vector. I keep the general notation the same but use a different superscript for these investors.

Let $Y_t^u = \left(s_t^*, s_{t-1}^*, ..., s_{t-T+1}^*, z_t^*, z_{t-1}^*, ..., z_{t-T+1}^*\right)$ be the new information vector for uninformed investors. Less-informed investors use only the public signal and the exchange rate to provide information on the vector of unobservables ξ_t. These signals are demonstrated as:
$s_t^* = a_1\varepsilon_{t+T}^f + a_2\varepsilon_{t+T-1}^f + ... + a_T\varepsilon_{t+1}^f + b_1\varepsilon_t^b + b_2\varepsilon_{t-1}^b + ... + b_T\varepsilon_{t-T}^b + c_1\varepsilon_t^z + c_2\varepsilon_{t-1}^z + ... + c_T\varepsilon_{t-T}^z$
and $z_t^* = d_1\varepsilon_{t+T}^f + d_2\varepsilon_{t+T-1}^f + ... + d_T\varepsilon_{t+1}^f + \varepsilon_t^z + \rho_z\varepsilon_{t-1}^z + \rho_z^2\varepsilon_{t-2}^z + ...$

Thus, the known component is written as[6]:

[5] Appendix A shows how H, $\widetilde{P}$ and R are represented in matrix format.
[6] Matrix notation for H^u can be found in appendix A.

$$Y_t^u = H^{u\prime}\xi_t, \tag{15}$$

and the conditional expectation is written as:

$$\begin{aligned} E_t(\xi_t) &= M^u Y_t^u \\ \text{where } M^u &= \widetilde{P} H^u \left[H^{u\prime} \widetilde{P} H^u \right]^{-1}, \end{aligned} \tag{16}$$

and $\widetilde{P}$ is again the unconditional variance of ξ_t. The conditional variance of ξ_t, $P^u \equiv var(\xi_t)$, is given by $P^u = \widetilde{P} - M^u H^{u\prime} \widetilde{P}$.

3.3 Tracing Out the Solution

First, I derive σ^2 by substituting $var(\xi_t)$ into equation (12). The next step is to write average expectation of tomorrow's exchange rate in terms of innovations. This is done by combining equations (13) and (14) for informed investors and (15) and (16) for uninformed investors. The resulting representation becomes:

$$\begin{aligned} \overline{E}_t(s_{t+1}) &= (1-\omega)\,\Theta' M H' \xi_t + \omega \Theta' M^u H^{u\prime} \xi_t \\ &\quad + A^*(L)\,\varepsilon_t^f + B^*(L)\,\varepsilon_{t-T}^b + C^*(L)\,\varepsilon_{t-T}^z, \end{aligned} \tag{17}$$

and I use the expressions of $\overline{E}_t(s_{t+1})$ and σ^2 to solve a fixed point problem by equating these equations to the conjectured exchange rate. This yields the solutions for coefficients of $A(L)$, $B(L)$ and $C(L)$ polynomials[7] and hence a representation for the equilibrium exchange rate in terms of innovations. This representation allows for the impulse response functions and the analysis presented in the next section.

[7] A description of the solution for the coefficients can be found in appendix B.

4 Analysis and Results

4.1 Impulse Response Functions

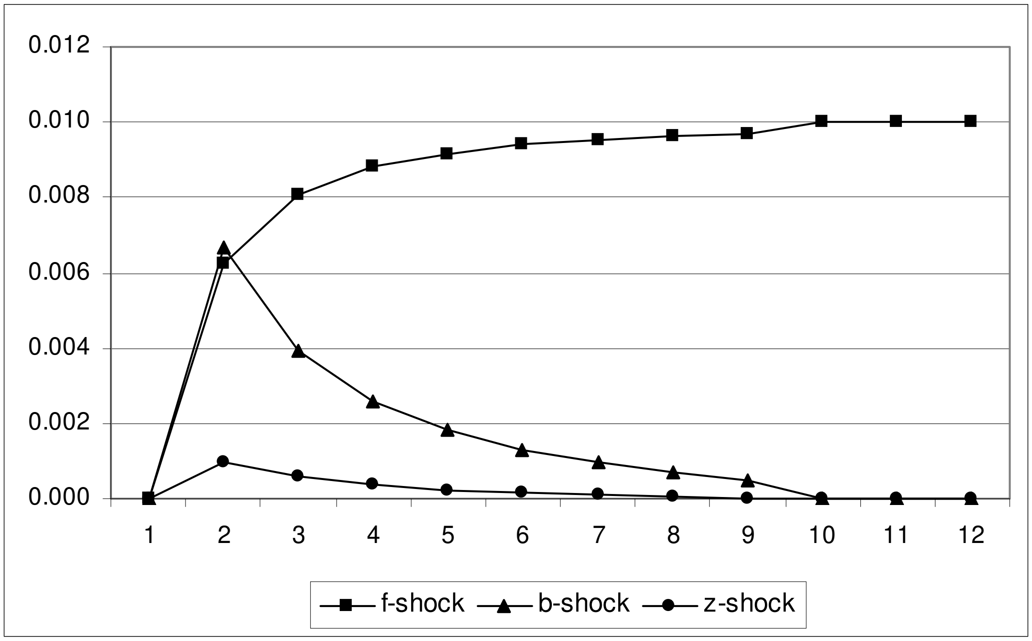
Figures 1 through 4 show the dynamic impact of one-standard-deviation shock on the exchange rate for different levels of asymmetric information in the market. The shocks are innovations to future fundamentals, innovations to aggregate hedge demand (which represent changes in non-fundamentals) and innovations to public signal. To be able to derive direct comparison with Bacchetta and Van Wincoop (2006), I follow their parameterization and set standard deviations of all shocks to 0.01 except for that of public shock, which is 0.08. Other parameters used are $T = 8, \alpha = 10, \gamma = 500$ and $\rho_b = 0.8$. Note that the model presented in Bacchetta and Van Wincoop (2006) allow only for the analysis of cases where ω is equal to 0 and 1. This model also allows for analysis when ω is between 0 and 1.

When each shock is analyzed separately, it is clear that the instantaneous response of the exchange rate to public shocks is highest in figure 4, when 90 percent of investors are receiving only public signal and only the remaining 10 percent are receiving both the public and the private signal. Naturally, magnitude of this response is lowest for figure 1 when $\omega = 0.1$. This magnitude increases as ω increases.

When the instantaneous response of the exchange rate to future fundamental shocks is analyzed, figure 1 depicts the case with the biggest response. This is true because there is more information about future fundamentals in the market due to very high proportion of the investors receiving both public and private signals. The response decreases as ω increases.

A more surprising result is the instantaneous response of the exchange rate to the change in non-fundamentals (b-shocks). It is obvious in figures 1 through 4 that impact of b-shocks is substantial in all four cases. The impact increases as ω increases since less information about future fundamentals causes a bigger (rational) confusion. When compared to the findings of Bacchetta and Van Wincoop (2006), this postulates that every investor in the market does not need to receive a private signal to create high magnitudes of disconnect. Actually, a small amount of private information in the market is enough to cause the biggest instantaneous response of

Figure 1: Impulse Response Function (w=0.1)



exchange rates to non-fundamental shocks.

Impulse response functions also show that as ω increases, persistence of the non-fundamental shocks increases as well. This means that when only 10 percent of investors are informed, confusion due to non-fundamentals lasts the longest in the economy. As a result, that is also the case when a shock to future fundamentals take the slowest path while converging to its true level.

5 Concluding Remarks

In this paper, I extend the results of Bacchetta and Van Wincoop (2006) by introducing a mechanism that allows the researcher to change the proportion of informed-to-uninformed investors in the market. This is achieved by allowing every investor in the model to receive a noisy public signal about future fundamentals but only a proportion of investors receiving their own noisy private signal on top the public signal they receive. The main findings are that as there is a higher proportion of informed investors in the market, the effect of a shock to future fundamen-

Figure 2: Impulse Response Function (w=0.3)

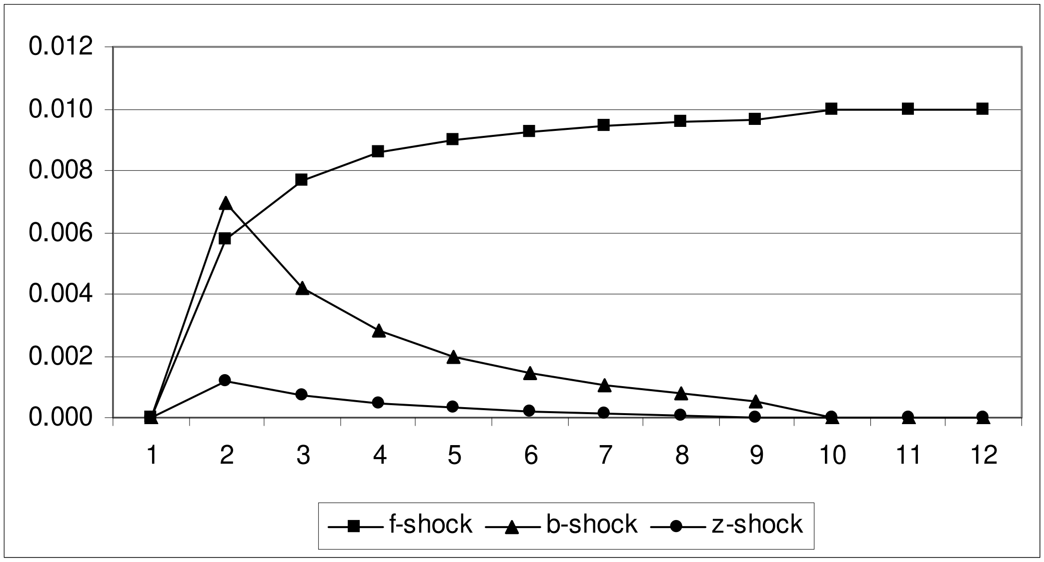


Figure 3: Impulse Response Function (w=0.6)

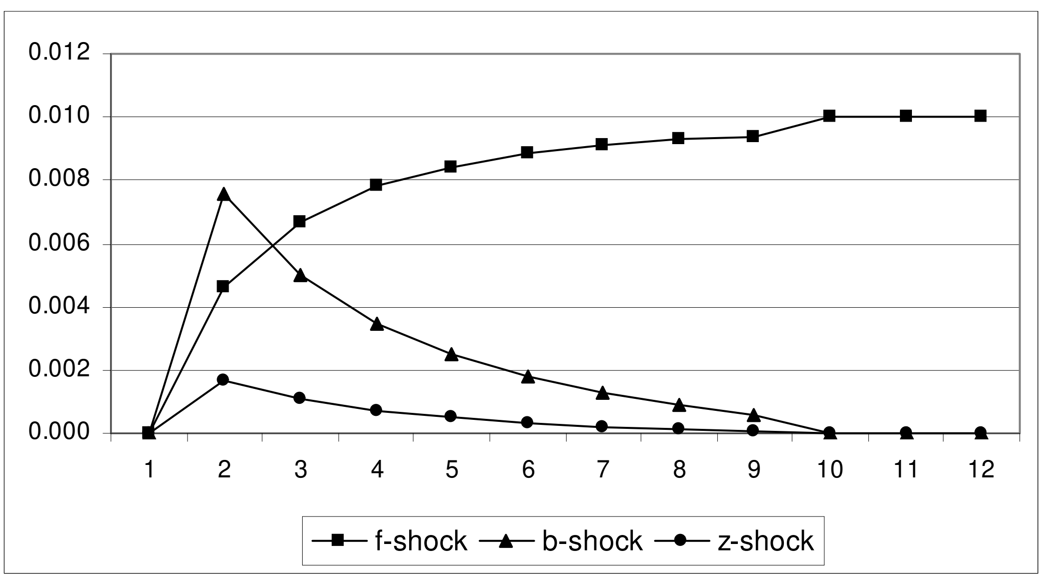
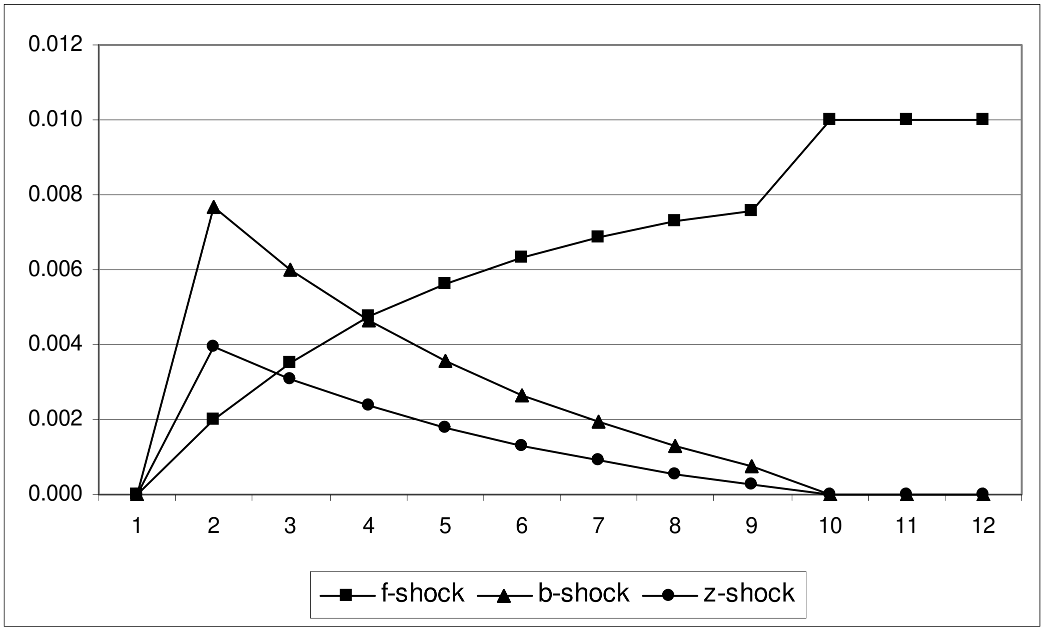


Figure 4: Impulse Response Function (w=0.9)



tals on the exchange rate is higher. Also, the effect of a non-fundamental shock on the exchange rate is relatively high in the model as long as there is asymmetric information (due to rational confusion). Surprisingly, a shock to non-fundamentals has the biggest effect on the exchange rate when the proportion of informed investors in the market is the smallest (10 percent). In other words, rational confusion is the biggest when the amount of aggregate information about future fundamentals in the economy is the lowest[8].

This paper offers a general model to match different foreign exchange markets with different levels of PIN measures, as presented in Marsh and O'Rourke (2005). It also suggests that while the disconnect between macro fundamentals and the exchange rate arises from information asymmetry, the magnitude of this disconnect can differ from one currency market to another. Results also show that only a small proportion of informed investors is all needed to create the disconnect in any market. In conclusion, if one wanted to strengthen the connection between exchange rates and macroeconomic fundamentals in any foreign exchange market, increasing the

[8]Note that this confusion is at its lowest level when no investor receives a private signal, as shown in Bacchetta and Van Wincoop (2006). There is very little disconnect in the economy in that situation.

proportion of investors holding more information (maybe through information disclosure) might be a good idea.

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A Appendix A

Matrices H and H^u and the unconditional variances of ξ_t and w_t^i ($\widetilde{P}$ and R respectively) are as follows.

$$H = \begin{bmatrix} a_1 & a_2 & . & a_T & b_1 & b_2 & . & b_T & c_1 & c_2 & . & c_T \\ 0 & a_1 & . & a_{T-1} & 0 & b_1 & . & b_{T-1} & 0 & c_1 & . & c_{T-1} \\ & & & & & & . & & & & & \\ 0 & 0 & . & a_1 & 0 & 0 & . & b_1 & 0 & 0 & . & c_1 \\ d_1 & d_2 & . & d_T & 0 & 0 & . & 0 & 0 & 0 & . & 0 \\ 0 & d_1 & . & d_{T-1} & 0 & 0 & . & 0 & 0 & 0 & . & 0 \\ & & & & & & . & & & & & \\ 0 & 0 & . & d_1 & 0 & 0 & . & 0 & 0 & 0 & . & 0 \\ d_1 & d_2 & . & d_T & 0 & 0 & . & 0 & 1 & \rho_z & . & \rho_z^{T-1} \\ 0 & d_1 & . & d_{T-1} & 0 & 0 & . & 0 & 0 & 1 & . & \rho_z^{T-2} \\ & & & & & & . & & & & & \\ 0 & 0 & . & d_1 & 0 & 0 & . & 0 & 0 & 0 & . & 1 \end{bmatrix}_{3TX3T}$$

$$H^u = \begin{bmatrix} a_1 & a_2 & . & a_T & b_1 & b_2 & . & b_T & c_1 & c_2 & . & c_T \\ 0 & a_1 & . & a_{T-1} & 0 & b_1 & . & b_{T-1} & 0 & c_1 & . & c_{T-1} \\ & & & & & & . & & & & & \\ 0 & 0 & . & a_1 & 0 & 0 & . & b_1 & 0 & 0 & . & c_1 \\ & & & & & & & & & & & \\ d_1 & d_2 & . & d_T & 0 & 0 & . & 0 & 1 & \rho_z & . & \rho_z^{T-1} \\ 0 & d_1 & . & d_{T-1} & 0 & 0 & . & 0 & 0 & 1 & . & \rho_z^{T-2} \\ & & & & & & . & & & & & \\ 0 & 0 & . & d_1 & 0 & 0 & . & 0 & 0 & 0 & . & 1 \end{bmatrix}_{2TX3T}$$

$$
\widetilde{P} = \begin{bmatrix}
\sigma_f^2 & 0 & . & . & 0 & 0 & 0 & . & . & 0 & 0 & . & . & 0 & 0 \\
0 & \sigma_f^2 & & & 0 & 0 & & & & . & . & & & & 0 \\
. & & . & & . & 0 & & & & . & . & & & & 0 \\
. & & & . & . & 0 & & & & . & . & & & & 0 \\
0 & . & . & . & \sigma_f^2 & 0 & 0 & .. & & 0 & 0 & . & . & 0 & 0 \\
0 & 0 & . & . & 0 & \sigma_b^2 & 0 & . & . & 0 & 0 & 0 & . & . & 0 \\
0 & & & & 0 & 0 & \sigma_b^2 & & & & 0 & & & & 0 \\
. & & & & 0 & . & & . & & . & & & & & 0 \\
. & & & & 0 & . & & & . & . & & & & & 0 \\
0 & 0 & . & . & 0 & 0 & & . & . & \sigma_b^2 & 0 & 0 & . & . & 0 \\
0 & 0 & . & . & 0 & 0 & 0 & . & . & 0 & \sigma_z^2 & 0 & . & . & 0 \\
0 & & & & . & . & & & & . & 0 & \sigma_z^2 & & & 0 \\
. & & & & . & . & & & & . & . & & & & . \\
. & & & & . & . & & & & . & . & & & & . \\
0 & 0 & . & . & 0 & 0 & 0 & . & . & 0 & 0 & 0 & . & . & \sigma_z^2
\end{bmatrix}_{3TX3T}
$$

and

$$
R = \begin{bmatrix}
0 & . & . & . & 0 & 0 & 0 & 0 & . & . & 0 & 0 \\
. & & & & & & & & & & & . \\
. & & & & & & & & & & & . \\
0 & . & . & & 0 & 0 & 0 & 0 & & . & 0 & 0 \\
0 & . & . & 0 & \sigma_v^2 & . & . & \sigma_v^2 & 0 & . & . & 0 \\
. & & & 0 & . & & & . & . & 0 & & . \\
. & & & 0 & . & & & . & . & 0 & & . \\
0 & . & . & 0 & \sigma_v^2 & . & . & \sigma_v^2 & 0 & . & . & 0 \\
0 & . & . & & 0 & 0 & 0 & 0 & & . & 0 & 0 \\
. & & & & & & & & & & & . \\
. & & & & & & & & & & & . \\
0 & . & . & . & 0 & 0 & 0 & 0 & . & . & 0 & 0
\end{bmatrix}_{3TX3T}
$$

B Appendix B

There is need to solve only finite amount of coefficients since for lags T and greater, coefficients can be derived from each other using the following equations:

$$
\begin{aligned}
a_{T+1+s} &= \frac{1+\alpha}{\alpha} a_{T+s} - \frac{1}{\alpha} d_s \\
b_{T+s+1} &= \frac{1+\alpha}{\alpha} b_{T+s} + \gamma \sigma^2 \rho_b^{T+s-1} \\
c_{T+1+s} &= \frac{1+\alpha}{\alpha} c_{T+s} \quad for\ all\ s \geqslant 1
\end{aligned}
$$

The method I use to find the conjectured coefficients is to assume starting values for them, solve the equilibrium exchange rate equation using those starting values and use the newly found values as new starting values and keep iterating and solving the equilibrium exchange rate equation until little or no change in the values is realized.