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ABSTRACT

Both the literature and new empirical evidence show that exchange rate regimes differ primarily by the noisiness of the exchange rate, not be measurable macroeconomic fundamentals. This motivates a theoretical analysis of exchange rate regimes with noise traders. The presence of noise traders can lead to multiple equilibria in the foreign exchange market. The entry of noise traders both create and share the risk associated with exchange rate volatility. In such circumstances, monetary policy can be used to lower exchange rate volatility without altering macroeconomic fundamentals.

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1 Introduction

Why are floating exchange rates so volatile?

In making his celebrated case for flexible exchange rates, Friedman (1953) argued:

> "... instability of exchange rates is a symptom of instability in the underlying economic structure. A flexible exchange rate need not be an unstable exchange rate. If it is, it is primarily because there is underlying instability in the economic conditions... "

Friedman's argument is that exchange rate instability is a manifestation of *economic volatility*. Exchange rate regimes differ in the mechanisms through which this underlying volatility is channeled. For instance, "liquidity" shocks may affect the nominal exchange rate if the latter floats, but the money supply if the rate is fixed. Underlying systemic volatility cannot be *reduced* by the regime, only *channeled* more or less efficiently. The economy can be thought of as a balloon; squeezing volatility out of one part (e.g., the exchange market) merely transfers the volatility elsewhere.[1]

How then to explain the volatility of floating exchange rates? Flotations of fixed exchange rates should lead only to *temporary* increases in exchange rate turbulence, so long as the underlying economic volatility does not change.[2] But for over a decade economists have known that exchange rate variability is much higher in fixed exchange rate regimes than in floats; we provide references and more evidence below.

In theory, exchange rate variability could vary with the exchange rate regime because of variations in underlying fundamental economic volatility. After all, the exchange rate regime is *chosen* by the policy authorities. Unfortunately, there is remarkably little evidence of a systematic relationship between the exchange rate regime and macroeconomic phenomena. A number of researchers have shown that the variability of observable macroeconomic

[1]Much of the argument here is common with Flood and Rose (1998).

[2]It is thus unsurprising that many were surprised and struck by the magnitude of the increase in exchange rate volatility rates following the shift towards generalized floating in 1973, e.g., Mussa (1979) or Obstfeld (1995). Indeed, much of the most influential work in international finance during the 1970s and 1980s was geared towards rationalizing the apparently high level of floating exchange rate volatility; Dornbusch (1976) is a classic example.

variables such as money, output, and consumption do not differ systematically across exchange rate regimes; again, we provide evidence below.

Simply put, *countries with fixed exchange rates have less volatile exchange rates than floating countries, but macro-economies which are equally volatile*, at least to a first approximation. This finding is inconsistent with theories which model either a) the exchange rate, or b) the exchange rate regime as manifestations of underlying economic shocks. It is therefore unsurprising that both classes of theories work badly in practice. The former has been well known at least since the work of Meese and Rogoff (1983). But the latter is the focus of this paper. Not only do macroeconomic models have no predictive value for floating exchange rates, they cannot even explain the difference in exchange rate volatility between fixed and flexible regimes.

This set of observations motivates our paper. Our objective is to establish and account for the stylized fact that exchange rate volatility differs systematically across exchange rate regimes in the apparent absence of corresponding differences in macroeconomic volatility. We are interested in developing a theoretical framework which can rationalize this phenomenon.

How can one model exchange rate regimes without relying on (nonexistent) differences in macroeconomic fundamentals? Since the only obvious cross-regime difference is in the behavior of the exchange rate, we focus our attention on the structure of the foreign exchange markets themselves. Our main theme is that a theory of exchange rate regimes cannot ignore the micro-structure of the foreign exchange market. Rather than assume that it is exogenous, we endogenize the structure of the markets. Of course, since monetary policy lies at the core of any theory of the exchange rate regime, macroeconomic fundamentals cannot be ignored altogether. What is required is an integration of a micro-structural theory of market volatility and a macroeconomic theory of exchange rate determination. In this paper we provide an example of such a theory.

To develop a formal theory we need to give content to the notion of microstructure of the foreign exchange market. The model that we propose is based on "noise trading", that is trading based on whims, fads and nonfundamental influences. We make a distinction between foreign exchange markets where a large fraction of traders are noise traders and those where noise trading is absent or negligible. We identify the microstructure of the market with the composition of the pool of foreign exchange traders who operate in the market. Exchange rate volatility, as a result, has two compo-

nents: fundamentals and noise. The size of the second component depends on the structure of the market.

To show that the exchange rate regime affects the presence of noise traders, we compare two stances for the monetary authority. In a "target zone" the monetary authorities commit themselves to maintain the volatility of the exchange rate below a reference value. In a pure float, by way of contrast, monetary policy is set independently from developments in the foreign exchange market. We demonstrate that a pure float may give rise to multiple equilibria.[3] In particular, there is sometimes an equilibrium with low exchange rate volatility and a low number of noise traders, which exists along with a high exchange rate volatility equilibrium with many noise traders. Since these equilibria exist for the same level of "fundamental" macroeconomic volatility, our model is able to rationalize the stylized fact which macroeconomic models cannot. The reason behind the multiplicity of equilibria is that in equilibrium, noise traders tend to cluster in the same markets, as is standard in many models of noise trading (e.g., Admati and Pfleiderer, 1988). The entry of noise traders in the market for a particular currency changes the structure of risks and returns in a way that makes it more attractive for other noise traders to join. This results in herd-like behavior in the migration of noise traders across markets, although their entry decisions are individually rational.[4]

A target zone makes it possible to pin down the economy on the equilibrium with low exchange rate volatility. A target zone implies a commitment to make monetary policy responsive to the entry of noise traders in the foreign exchange market. The monetary authorities offset any increase in exchange rate volatility induced by the arrival of noise traders, by reducing the volatility of monetary fundamentals. This effectively insulates exchange rate volatility from potential changes in the structure of the foreign exchange market. By discouraging the entry of noise traders, the potential for multiple equilibria disappears and the economy stays at an equilibrium with low exchange rate volatility. Thus, the mere promise that the authorities will react to the entry of noise traders, if it is believed, suffices to keep noise traders

[3]The multiplicity of equilibria is also a feature of Flood and Marion (1996) and Flood and Rose (1998), who use a more primitive stochastic portfolio-balance model with a regime-varying risk premium and homogeneous agents. See also Hau (1998).

[4]The decisions of noise traders whether or not to enter a particular market are rational in the sense that they are made on the basis of utility maximization.

away.

De Long et. al. (1990) first formalized noise trading in a purely domestic context. A few papers have subsequently introduced noise trading in the context of foreign exchange.[5] Mark and Wu (1998) make some progress on the forward discount puzzle by investigating uncovered interest parity in a model with noise traders. Faruqee and Redding (1999) show that the entry of liquidity providers can accelerate the reversion of the exchange rate towards its fundamental value in an environment with noise traders. A closer precursor to our paper is Hau's (1998) analysis of the free entry of traders with noisy expectations into a foreign exchange market. Hau finds that temporary noise may result in higher exchange rate volatility and multiple equilibria as we do, but abstracts from explicit consideration of macroeconomic or monetary policy. More generally, these papers do not share our focus on exchange rate regimes.

The paper which is closest in spirit to our analysis of target zones is Krugman and Miller (1993). Krugman and Miller argue that the real policymakers' motivation in instituting target zones is the hope that they will protect their currencies from pure speculative movements that are not related to the fundamentals. They show that a target zone may reduce exchange rate volatility in a model with stop-loss traders.

The paper is structured as follows. In section 2 below, we present the stylized empirical facts of macroeconomic volatility and exchange rate regimes. We show that standard macroeconomic models cannot be used to understand the data. We then proceed to the core of the paper in section 3, which presents a model of the foreign exchange markets with an endogenously determined number of noise traders. We use the model to analyze monetary policy, and discuss the relevant empirical evidence. The paper concludes with a brief summary and suggestions for future research.

[5]There is a related literature which examines the (de-)stabilizing nature of speculation in foreign exchange markets which does not involve noise trading. For example, Carlson and Osler (1997) show that rational speculation can be destabilizing. Frankel and Froot (1990) argue that feedback trading rules can increase exchange rate volatility.

2 A Macroeconomic Mystery

We have two objectives in this section of the paper. First, we establish one stylized fact. We show that exchange rate volatility varies systematically and dramatically across exchange rate regimes, while observable macroeconomic volatility does not. Second, we show that macroeconomic models cannot allow one to understand this finding.

The main purpose of this paper is to provide a theoretical framework consistent with stylized facts, rather than to establish the latter with new empirics. Consequently, we are at pains in this section to show that our interpretation of the data is consistent with existing work and is not particularly sensitive to measurement issues. We use a variety of sources from the literature to support our case. The evidence is univariate and multivariate, structural and non-structural, and exploits differences across both countries and time.

Mussa (1986) established convincingly that nominal and real exchange rate variability varies substantially and systematically with the exchange rate regime. Mussa used bilateral dollar exchange rates for a variety of industrial countries from 1957 through 1984. He showed that the variance of real exchange rates was an order of magnitude greater in the floating period *after* the Bretton Woods period, than it was *during* the Bretton Woods regime of pegged rates.[6] In his comment on Mussa, Black (1986) argued that "empirical workers in the field of exchange rates will not regard this as new information" and cites work which precedes Mussa's.[7] Mussa's evidence is especially convincing to us for two reasons. First, it is essentially undisputed, at least to our knowledge. Second, the objective of Mussa's paper is unrelated to ours: Mussa was interested in rejecting exchange rate models with flexible prices.

Baxter and Stockman (1989) extended Mussa's work on exchange rates to other macroeconomic variables. Using data for a variety of OECD and developing countries, Baxter and Stockman examine the variability of out-

[6]Mussa's "first important regularity" is "The short term variability of real exchange rates is substantially larger when the nominal exchange rate between these countries is floating rather than fixed."

[7]Certainly Stockman (1983) provides consistent evidence earlier. See also Aliber (1976) and other references given by Black.

put, trade variables, and both private and government consumption, using different de-trending techniques. They are "unable to find evidence that the cyclic behavior of real macroeconomic aggregates depends systematically on the exchange-rate regime. The only exception is the well-known case of the real exchange rate."

The evidence presented by Mussa, Baxter and Stockman is compelling, but incomplete. It relies on differences in the behavior of individual countries across time. Time-specific effects may confound such empirical work. Examining the behavior of a cross-section of countries during a single time-period is a way to check the stylized fact for consistency, and is also of intrinsic interest. Further, the analysis is univariate. Models which link changes in exchange rate volatility explicitly to changes in macroeconomic volatility are potentially useful adjuncts, since the latter effects can be potentially subtle and difficult to uncover with univariate techniques. Most importantly, it is only by using macroeconomic models that we will be able to reveal their inability to explain the phenomenon with which we are concerned.

These objections have been addressed by the work of Flood and Rose (1995). They begin with the conventional monetary model of the exchange rate. A simple money market equilibrium is posited in the domestic "center" country, linking the natural logarithm of the money stock (m) deflated by the (log of the) price level (p) to the interest rate (i) at a point in time t; the same condition characterizes the foreign country (denoted with an asterisk). Prices are assumed to be perfectly flexible, and purchasing power parity is satisfied at all times so that the (log of the) price of foreign exchange (e) is simply the ratio of price levels. The model can be written:

$$m_t - p_t = -\alpha i_t \quad (1)$$

$$m_t^* - p_t^* = -\alpha i_t^* \quad (2)$$

$$e_t = p_t - p_t^* \quad (3)$$

so that:

$$e_t = (m_t - m_t^*) + \alpha(i_t - i_t^*). \quad (4)$$

The model's ability to explain exchange rate volatility can be tested by comparing the characteristics of the left- and right-hand sides of equation (4).

Figure 1 contains quarterly *time-series* evidence on Deutschemark exchange rates from 1959 through 1996 for twenty OECD countries; this represents the left-hand side of equation 4. Comparable evidence for the right-hand side is portrayed in Figure 2; we use M1 and short maturity money market interest rates, and a consensus estimate from the literature for the interest semi-elasticity of money demand (unity).[8,9]

The message from the two figures is straightforward. Consistent with Mussa's finding, Figure 1 shows that nominal exchange rate variability is low when exchange rates are fixed (in the 1960s or for strict EMS peggers like Austria and the Netherlands), and high when exchange rates float. But macroeconomic fundamentals (as dictated by equation (4)) do *not* exhibit regime-varying volatility in Figure 2.

Comparable *cross-section* evidence is available in Figure 3. For each of the twenty countries, the standard deviation of the exchange rate (estimated for each country over time) is graphed against the standard deviation of the right-hand side of equation (4). For generality, we use the United States in place of Germany as the reference country. There is again no evidence of any clear relationship between macroeconomic and exchange rate volatility.[10]

It might be objected that the empirical rejection of equation (4) is hardly surprising since it is derived from assumptions, in particular instantaneous PPP, that are notoriously rejected by the data. The main result, however, turns out to be very robust to changes in model specification. For instance, Flood and Rose (1995) extend the model to include the effects of sticky prices, real income, random shocks, and a variety of other issues without changing the results. The intuition behind this insensitivity is simple: such extensions simply make the right-hand side of equation (4) more complicated combinations of money, output, interest rates, and prices, and lags. Flood and Rose found that they could not match the volatility characteristics of

[8]The data set is taken from the International Monetary Fund's *International Financial Statistics* CD-ROM, and has been checked for errors. It is available as a STATA data set at http://haas.berkeley.edu/~arose.

[9]Flood and Rose (1995), show that the argument holds for a very wide range of reasonable parameter values.

[10]These ocular results can be verified more formally with statistical tests, as in Flood and Rose (1995). For instance, the regression slope for the data portrayed in Figure 3 is slightly negative with a t-statistic of 0.1.

exchange rates to those of structural economic fundamentals, even allowing for stochastic structural disturbances. In particular, traditional economic fundamentals of structural models do not have the regime-varying volatility needed to match the regime-varying volatility of exchange rates. Where Flood and Rose provide structural evidence across time for a number of countries, Rose (1994) provides comparable cross-country data, with similar results.

3 A Micro-Structural Theory of Exchange Rate Regimes

The analysis in the preceding section makes us pessimistic about the ability of purely macroeconomic models to explain regime-varying exchange rate volatility. An alternative strategy is to consider models where the *structure* of the foreign exchange market changes with the exchange rate regime.

The model we present mixes elements from two hitherto disparate branches of economic theory, the macroeconomic theory of exchange rate determination, and the noise trading approach to asset price volatility. As in chemistry, we make the experiment illuminating by combining two components which are as pure as possible. Thus, we pick simple conventional building blocks, uncontaminated by tangential complications. On the macroeconomic side, we use the conventional monetary model of the exchange rate, augmented by portfolio considerations. On the micro-structure side we employ the model of noise trading developed by De Long *et al.* (1990). As shown above, the macroeconomic part of the model performs poorly by itself. We now show that one can improve the fit of the model by, paradoxically, adding noise.

In the model we present, exchange rate volatility has two components: macroeconomic fundamentals and noise which is unrelated to fundamentals. The size of the noise component is endogenously determined; it depends on the decisions of noise traders who decide whether or not to enter the foreign exchange market. Their decisions to enter depend in turn, on the volatility of the exchange rate and the risk premium on foreign bonds. Thus, monetary policy determines the exchange rate not only directly, by changing the relative money supplies, but also indirectly, by affecting the *composition*

of the foreign exchange market.

3.1 Macroeconomic Fundamentals

We continue to maintain (1)-(3), so that simple monetary equilibria hold and purchasing power parity is satisfied continuously. We further assume that the domestic country is in a steady state with constant money supply, interest rate and price level. Hence the expression for the exchange rate can be re-written dropping the time index for domestic variables:

$$e_t = (m - m_t^*) + \alpha(i - i_t^*). \tag{5}$$

We initially assume that the difference between domestic and foreign money supplies, $m - m_t^*$, follows a stochastic i.i.d. normal process centered on zero. This variable will assume the role of economic "fundamentals" in the remainder of the analysis.[11] For the moment we assume that this policy variable is exogenous, as would be appropriate if the exchange rate floats freely. We relax this assumption when we consider official exchange rate policy below.

The interest rate is determined by equilibrium in the international bonds market. We assume that investors in the international bonds market care about the return of their portfolio measured in terms of domestic currency. The domestic currency may be viewed as the international currency which serves as the standard of comparison in evaluating portfolio returns.[12] Investors are risk averse and require a risk premium to hold bonds denominated in foreign currency.

The quantity of foreign external liabilities results, in equilibrium, from the foreign current account and the balance of payments. These external

[11]Since we maintain this structural equation throughout our analysis, our model cannot rationalize the Flood-Rose (1995) mystery discussed above.

[12]Implicitly we think of the domestic country as large and the foreign country as a small open economy. One could make the model more symmetric by assuming that *some* investors care about their portfolio returns in terms of foreign currency, or that all investors evaluate their returns in terms of a currency basket. This would make the risk premium on foreign currency denominated bonds lower in equilibrium, but the essential properties of the model would remain the same. Note also that one does not need to make the distinction between nominal and real returns in terms of domestic currency since the domestic price level is constant.

liabilities may take the form of bonds denominated in either currency. The supply of bonds denominated in foreign currency results from the foreign fiscal and monetary authorities' actions, in particular the respective shares of domestic- and foreign currency-denominated bonds on the asset side of the central bank's balance sheet. We assume hereafter that the foreign authorities maintain the supply of foreign currency denominated bonds, expressed in terms of domestic money, at a constant level $\overline{B}$. This assumption is made for the sake of analytical convenience, and can be relaxed without changing the thrust of our results.[13]

3.2 Micro-Structure: Trading Behavior

Foreign exchange traders are modelled as overlapping generations of investors who live for two periods and allocate their portfolio between domestic and foreign one-period nominal bonds in the first period of their life. Traders have the same endowments and tastes, but differ in their ability to trade in the foreign bonds market. Some of them are able to form rational expectations on risk and returns costlessly, while others have noisy expectations and must pay an entry cost to invest in foreign bonds. We refer to the former as "informed" traders and the latter as "noise" traders. Noise traders trade on the basis of fads which are unrelated to fundamentals; informed traders do not (though they have no special information advantage). Noise traders also have higher costs of market participation than informed traders.

At each period the new-born traders form a continuum of measure 2 $j \in [0, 2]$. Each individual trader j receives an endowment of W units of domestic currency. She then decides whether or not to enter the foreign bonds market. We denote by δ_t^j the dummy variable characterizing the entry decision of trader j at time t; it equals one if she enters, zero if not. Traders enter the market for foreign bonds if this increases their utility. Trader j's entry decision is taken before the time t monetary policy shock is revealed, on the basis of the information available at $t-1$:

[13] *Some* assumption is needed, since there is no natural way to endogenize the currency composition of the foreign country's external debt. The assumption we make has the advantage of keeping the model simple. It would not be very difficult to consider alternatives, such as a stochastic supply of foreign currency denominated bonds.

$$\forall j,\ t \qquad \delta_t^j = 1 \Longleftrightarrow \mathrm{E}_{t-1}^j(U_t^j|\delta_t^j = 1) \ \geq \ \mathrm{E}_{t-1}^j(U_t^j|\delta_t^j = 0) \tag{6}$$

where U_t^j is the utility of a new-born trader j at time t, and the expectations operator bears the trader's index to allow for heterogeneity (the expectations operator without index denotes the rational expectation).

A trader who has entered the foreign bonds market invests b_t^j in foreign bonds so as to maximize the expected utility of her end-of-life wealth, expressed in terms of the domestic currency. We assume that trader j's portfolio allocation problem at time t is:

$$max_{b_t^j} U_t^j = \mathrm{E}_t^j \left(-exp(-aW_{t+1}^j)\right) \tag{7}$$

where W_{t+1}^j is the end-of-life wealth of trader j. It is given by:

$$W_{t+1}^j = (1+i)W + \delta_t^j(b_t^j \rho_{t+1} - c_j). \tag{8}$$

Trader j's end-of-life wealth is equal to the trader's initial endowment times the yield of domestic bonds plus, if j enters, the excess return on foreign bonds minus a fixed cost that must be borne in order to enter the foreign bonds market. The excess return on foreign bonds between t and $t+1$ is given by:

$$\rho_{t+1} = i_t^* + (e_{t+1} - e_t) - i \tag{9}$$

The cost c_j reflects the costs associated with entering the foreign market for trader j.[14] We assume that foreign exchange traders are heterogeneous with respect to this cost.

There are two types of traders: *informed* traders, located in the interval $[0,1]$, and *noise* traders, in $(1,2]$. Informed investors have an accurate knowledge of the way the exchange rate is determined, and bear no entry cost.[15] They are knowledgable about the economy, can process new information costlessly and make their decisions on the basis of rational expectations about the future. Thus, for $j \in [0,1]$ one can write:

[14]These costs are much discussed in the literature, and may include informational problems, tax issues, and other phenomena. There is no presumption that they are small, given the size of the "home market effect"; Lewis (1995) provides a survey.

[15]The assumption that informed investors bear no entry cost stems from our desire to focus on the entry decision of *noise* traders. It would not be very difficult, however, to generalize the model by making entry costly for all traders.

$$\mathrm{E}_t^j(\rho_{t+1}) = \mathrm{E}_t(\rho_{t+1}) \quad (10)$$
$$\mathrm{Var}_t^j(\rho_{t+1}) = \mathrm{Var}_t(\rho_{t+1}) \quad (11)$$
$$c_j = 0 \quad (12)$$

where $\mathrm{E}_t^j(\rho_{t+1})$ and $\mathrm{Var}_t^j(\rho_{t+1})$ are the expected value and conditional variance of the excess return on domestic bonds as evaluated by trader j at period t, and $\mathrm{E}_t(\rho_{t+1})$ and $\mathrm{Var}_t(\rho_{t+1})$ are their mathematical counterparts.

Noise traders, by way of contrast, have imperfect knowledge of the determinants of the exchange rate and bear a positive entry cost. We adopt the (standard) assumption that noise traders perceive the second moment of returns correctly, but allow their perception of first-moments to be affected by noise that is unrelated to economic fundamentals.[16] The noise is common across traders; there is no private information in the model. Moreover noise traders bear a strictly positive entry cost. Formally we assume that for $j \in (1, 2]$:

$$\mathrm{E}_t^j(\rho_{t+1}) = \overline{\rho} + \nu_t \quad (13)$$
$$\mathrm{Var}_t^j(\rho_{t+1}) = \mathrm{Var}_t(\rho_{t+1}) \quad (14)$$
$$c_j = \gamma \quad (15)$$

where $\overline{\rho}$ is the unconditional mean of the excess return (or average risk premium) and the noise term ν_t is a stochastic i.i.d. normal shock common across j and uncorrelated with m_t^*. We interpret the noise term as a fad which is wide-spread but non-fundamental. Unlike De Long *et al.* (1990), our noise traders do not make systematic errors in their prediction of excess returns.

We link the size of noise traders' errors to economic uncertainty by assuming that the variance of the noise is proportional to the true unconditional variance of the exchange rate:

$$\mathrm{Var}(\nu) = \lambda \, \mathrm{Var}(e) \quad (16)$$

[16]For evidence of bias in exchange rate expectations, see Frankel and Froot (1987).

where λ is a positive coefficient. (Assuming that $\text{Var}(\nu)$ is constant is less plausible; this would imply, for example, that noise traders expect the exchange rate to be stochastic when it is in fact constant.)

3.3 Equilibrium

An equilibrium in this model consists of stochastic processes for the exchange rate $\{e_t\}$, the risk premium $\{\rho_t\}$, and individual traders' decision rules $\{\delta_t^j\}$ and $\{b_t^j\}$, such that at each period t, δ_t^j satisfies the entry condition (6), b_t^j is the solution to the optimal portfolio allocation problem (7), and the market for domestic bonds is in equilibrium:

$$\overline{B} = \int_0^2 \delta_t^j \, b_t^j \, dj. \tag{17}$$

This equilibrium appears to be difficult to determine, since it involves entry decisions by a continuum of heterogeneous agents in a stochastic environment. However, we exploit the assumption that the monetary shock is independently and identically distributed, which suggests that the set of equilibrium individual decision rules takes a simple stable form.

We solve the model with a "guess-and-verify" technique, first postulating its properties, then checking that they are satisfied. We conjecture that:

(i) the fluctuations of the exchange rate are identically and independently distributed around an average level $\overline{e}$;

(ii) all informed traders, and a constant number of noise traders, n, enter the foreign bonds market at each period.

We characterize the equilibrium by proceeding in two steps. First, we determine the equilibrium exchange rate, taking the number of noise traders in the foreign market as given. We then endogenize the number of noise traders by using the no-entry condition.

3.4 Analysis with an Exogenous Number of Noise Traders

In equilibrium the foreign interest rate and the risk premium are identically and independently distributed around average values that we denote $\overline{i}^*$ and

$\overline{\rho}$ respectively. The average risk premium is equal to the average difference between the foreign and domestic nominal interest rates:

$$\overline{\rho} = \overline{i}^* - i \tag{18}$$

which, taking the expectation of equation (5), implies:

$$\overline{e} = -\alpha\overline{\rho} \tag{19}$$

A rise in $\overline{e}$ corresponds to an appreciation of the foreign currency. Equation (19) says that a higher average interest rate differential, by decreasing the demand for foreign money relative to domestic money, leads to the depreciation of the foreign currency.

The risk premium is determined by equilibrium in the market for bonds denominated in foreign currency. If the excess return on these bonds is normally distributed (which is true in equilibrium, as we show below), it is well-known that maximizing (7) is equivalent to maximizing the mean-variance objective function:

$$\mathrm{E}_t^j(W_{t+1}^j) - \frac{a}{2}\mathrm{Var}_t^j(W_{t+1}^j) \tag{20}$$

and the demand for bonds denominated in the foreign currency by an individual trader is given by:

$$b_t^j = \frac{\mathrm{E}_t^j(\rho_{t+1})}{a\mathrm{Var}_t^j(\rho_{t+1})}. \tag{21}$$

The equality of demand and supply in the bonds market implies:

$$\begin{aligned} \overline{B} &= \frac{\mathrm{E}_t(\rho_{t+1})}{a\mathrm{Var}_t(\rho_{t+1})} + n\frac{\overline{\rho} + \nu_t}{a\mathrm{Var}_t(\rho_{t+1})} \\ &= \frac{\mathrm{E}_t(\rho_{t+1}) + n(\overline{\rho} + \nu_t)}{a\mathrm{Var}(e)}. \end{aligned} \tag{22}$$

where n is the number of noise traders investing in the domestic bonds market. Taking the expectation of (22) at $t-1$ then gives an expression for the average risk premium:

$$\overline{\rho} = a\frac{\overline{B}}{1+n}\text{Var}(e). \tag{23}$$

The average risk premium is increasing with the variance of the exchange rate, the coefficient of absolute risk aversion and the quantity of bonds per trader. We can then derive the equilibrium exchange rate by substituting the definition of ρ_{t+1} into (22) and using (5) to substitute out the interest rate differential, which gives:

$$e_t - \overline{e} = \frac{m - m_t^*}{1+\alpha} + \frac{\alpha}{1+\alpha} n\nu_t. \tag{24}$$

This expression confirms that the fluctuations of the exchange rate are i.i.d. normal in equilibrium.

Taking the variance of (24) and using (16) to substitute out the variance of the noise allows us to close the characterization of equilibrium with an expression for exchange rate variability:[17]

$$\text{Var}(e) = \frac{\text{Var}(m - m^*)}{(1+\alpha)^2 - \lambda\alpha^2 n^2} \tag{25}$$

The variance of the exchange rate depends on fundamentals and noise. The fundamental component is proportional to the variance of money supply. The novelty in this model is the noise component, which is proportional to the square of the number of noise traders active in the market. An exogenous increase in the number of noise traders unambiguously increases the variance of the exchange rate, which tends to raise the risk premium. On the other hand, it also increases the total number of traders demanding foreign bonds, which lowers the risk premium. That is, noise traders have two counteracting roles in our model; they both a) create risk and b) share risk. As a result, the impact of the extra noise traders on the equilibrium risk premium is non-monotonic. The ambiguous effect of noise trading on the risk premium is portrayed in Figure 4. This ambiguity – the fact that the risk premium can be decreasing or increasing with the number of noise traders – lies at the heart of our model.[18]

[17]Note that this expression yields a positive value for the variance of the exchange rate for all $n \in [0,1]$ iff $\lambda < (1+\alpha)^2/\alpha^2$, a condition that we assume satisfied thereafter.

[18]Figures 4-8 were obtained for the following values of the parameters: $\alpha = 1$, $a = 4$, $\lambda = 3$, $\overline{B} = 1$, and $\gamma = 0.3$. The variance of relative money supply, $Var(m - m^*)$, was set

3.5 Endogenous Entry

We now endogenize the composition of the pool of active traders.

The entry decision for informed traders is trivial: they bear no entry cost and always enter the foreign bonds market in equilibrium. However, a noise trader enters only if the benefit of diversifying her portfolio into foreign bonds exceeds her cost of entry. We show in the appendix that this condition takes the form:

$$\mathrm{GB}(\overline{\rho}, \mathrm{Var}(e)) \geq \gamma \tag{26}$$

where GB($\overline{\rho}$,Var(e)), the gross benefit of entry for noise traders, is given by:

$$\mathrm{GB}(\overline{\rho}, \mathrm{Var}(e)) = \frac{1}{2a(1+\lambda)} \frac{\overline{\rho}^2}{\mathrm{Var}(e)} + \frac{1}{2a} \log(1+\lambda). \tag{27}$$

The partial derivatives of equation (27) have an intuitive interpretation. The benefit of entry, as assessed by noise traders, is increasing with the risk premium and decreasing with exchange rate variability. But in equilibrium both the risk premium and the variance of the exchange rate are functions of the number of noise traders that enter the foreign bond market; this can be seen in equations (23) and (25). This circularity, as we now show, can generate multiple equilibria.

We illustrate our result in Figures 5-7. These show the net benefit of entry for the marginal noise trader, for three different levels of the variance of (monetary) "fundamentals".[19] The benefit depends on the number of noise traders, n, as well as the impact that these noise traders have on exchange rate variability and the risk premium, Var(e) and $\overline{\rho}$.

Figure 5 portrays a low level of fundamentals variance. It shows that the only possible equilibrium is one in which noise traders do not enter the foreign bonds market. The variance of macroeconomic fundamentals is so low that the benefit of entry is always negative for the marginal entrant, however many noise traders are present.

Figure 6 is the more interesting case; it portrays an intermediate level of fundamental variance. There are two stable equilibria in this scenario,

to 1 in figure 4.

[19] $Var(m)$ was set to 0.5, 1.5 and 2.0 in Figures 5, 6 and 7 respectively.

corresponding to points A and C (point B is unstable). Point A corresponds to an equilibrium with low exchange rate volatility and a low risk premium. Here, the foreign market does not offer noise traders a large enough gain to induce many of them to enter. But there is another equilibrium at point C, which corresponds to a high volatility, high risk premium equilibrium. In this equilibrium, more noise traders are attracted to the foreign bonds market by the high risk premium *that they themselves generate by entering the market.* Thus, our model can generate different levels of exchange rate volatility for the same level of macroeconomic volatility. We can rationalize the stylized fact which motivated this paper by simply labeling point A a "fixed exchange rate regime" and point C a "floating exchange rate regime".

Figure 7 is symmetric to Figure 5; fundamental volatility is so high that there is only one equilibrium with high exchange rate volatility and noise traders present.

Figure 8 portrays the relationship between the variance of fundamentals and exchange rate volatility. The lower branch corresponds to equilibria in which noise traders do not enter the foreign markets (or only a small number of them do); the higher branch to equilibria with entry; and the branch in the middle to unstable equilibria. If the variance of fundamentals, $\text{Var}(m - m^*)$, is below a threshold there is a unique equilibrium as in Figure 5; noise traders stay away from the foreign market. If this variance is above a much higher threshold, the equilibrium is again unique since noise traders always enter (the Figure 7 case). In between the two thresholds there is a "zone of multiplicity." If the variance of fundamentals falls inside this intermediate range there are two stable equilibria. One has low exchange rate volatility and limited entry of noise traders; the many noise traders who are present in the other make the exchange rate more volatile.

Under a pure float, hence, there is no simple relationship between the volatility of monetary fundamentals and the exchange rate. Two countries with similar fundamentals may exhibit radically different levels of exchange rate volatility. In the high volatility equilibrium, exchange rate volatility is "excessive", in the sense that it is higher than the level that can be ascribed to the traditional macroeconomic fundamentals. This excessive volatility can be eliminated with a policy which switches equilibria, as we now show.

3.6 Exchange Rate Policy

The purpose of this section is to analyze policies that reduce exchange rate noise. These policies work by allowing the policymaker to co-ordinate activity to a low volatility equilibrium. We consider an exchange rate "target zone," following Krugman and Miller (1993).

Krugman and Miller argue that the main cost of floating exchange rates, as perceived by policy-makers, is that they leave currencies vulnerable to purely speculative price movements that are unrelated to fundamentals. They interpret a target zone as a mechanism designed to reduce exchange rate volatility by limiting the impact of these non-fundamental influences. Our model is well suited to a discussion of such issues.

Suppose that the foreign monetary authorities wish to implement the following monetary process:

$$m - m_t^* = \Delta\tilde{m}_t \tag{28}$$

where $\Delta\tilde{m}_t$ is an exogenous i.i.d. normal process.[20] In the absence of noise traders, this process implies the following exchange rate process:

$$\tilde{e}_t \equiv \overline{e} + \frac{\Delta\tilde{m}_t}{1+\alpha}. \tag{29}$$

This monetary regime can be characterized in two ways. Either the monetary authorities can announce a) that the money supply will fluctuate around a constant level with a given variance [Var($\Delta\tilde{m}$)], or b) that the exchange rate will fluctuate around its mean with a given variance [Var($\tilde{e}$) =Var($\Delta\tilde{m}$)/(1+ α)^2]. We identify the first type of announcement with a floating exchange rate and the second with an exchange rate target zone.

In the absence of noise traders, it does not matter whether the monetary regime is expressed in terms of the money supply or the exchange rate. Since these variables are linked by (29), specifying the process for $\{\Delta\tilde{m}_t\}$ is equivalent to specifying the process for $\{\tilde{e}_t\}$.

Things are different in the presence of noise traders, at least in the zone of multiplicity. Suppose that Var($\Delta\tilde{m}_t$) is in the range where multiple equilibria can arise. From Figure 8 we know that the monetary process is consistent

[20]We take this process as given. Our model does not allow us to derive the optimal policy rule from primitive policy objectives such as output stabilization, given its lack of nominal frictions.

with both a low exchange rate volatility equilibrium (point A) and a high exchange rate volatility equilibrium (point C). That is, specifying a monetary process leaves the composition of the foreign exchange market indeterminate and allows for multiple equilibria. Taking the monetary process (28) as an exogenous policy variable means that noise traders may rationally decide to enter the foreign market. If enough of them enter, the economy winds up at the high volatility equilibrium. Benign neglect of the exchange rate can result in excessive volatility.

A solution to the multiplicity problem is to announce an explicit objective of limiting the fluctuations of the exchange rate – a target zone. Suppose that the monetary authorities announce that they will implement the exchange rate process $\{\tilde{e}_t\}$ *irrespective* of the entry of noise traders. That is, the authorities commit themselves to the following money supply process:

$$m - m_t^* = (1 + \alpha)(\tilde{e}_t - \bar{e}) - \alpha n \nu_t. \tag{30}$$

This announcement, so long as it is credible, keeps noise traders away and pins down the economy on the equilibrium with low exchange rate volatility. This is because the exchange rate variance and the risk premium resulting from (29) are those that prevail in the low volatility equilibrium; they make noise traders prefer to stay out of the foreign bonds market. Such a target zone involves no sacrifice in terms of macro-fundamentals. Given that $n = 0$ in equilibrium, the money supply is in each period exactly at the level desired by the monetary authorities. There is a free lunch of exchange rate stability.

This policy analysis begs the question of why any country should *care* about exchange rate volatility at all. Our model has been kept highly stylized; it abstracts from country size, openness, and the nominal frictions that make exchange rate policy decisions non-trivial. Still, our main result – that reducing exchange rate volatility may not involve any sacrifice in terms of monetary autonomy – should remain valid in more complex models with nominal stickiness. This violates Mundell's "Incompatible Trinity" of fixed exchange rates, monetary autonomy and capital mobility. A threat by the monetary authority (to react if noise traders enter) changes the composition of the market. By discouraging the entry of noise traders, the market is steered to a low volatility equilibrium where intervention is unnecessary. Words speak loudly enough that actions are unnecessary.[21]

[21]By picking out a single equilibrium, the expectations "honeymoon" offered by the

3.7 Empirical Evidence

It is difficult to provide direct empirical support for our model. While it is possible to estimate exchange rate volatility and risk premia, there are few data available on foreign exchange trading volume. Information on *dis-aggregated* trading activity is even more rare.[22] These would be critical components of any serious test of our theory. However there are a few suggestive pieces of evidence which support our argument.

One key part of our model is the prediction that an increase in trading volume is associated with an increase in the level of exchange rate volatility, since the increase in volume comes, at the margin, from noise traders. To our knowledge, there are only two sources of data on exchange rate volume; both have problems.

The Chicago Mercantile Exchange has data series on volumes of trade in their futures markets. However, there are problems with the data set. First, it only includes futures market volume, ignoring spot markets, options and other derivatives. Second, the rates are all bilateral dollar rates. Third, there are gaps in the series. Fourth, there are only a limited number of currencies traded on the markets. Bearing these caveats in mind, it is still instructive to examine the data set.

As our regressor we use annual data on CME trading volume for the years 1973 through 1989.[23] These are available for the following currencies (vis-a-vis the American dollar): (British) pound sterling; Canadian dollar; (German) DM; (Italian) lira; (Japanese) yen; (Mexican) peso; Swiss franc; (Dutch) guilder; French franc; and Australian dollar. As our regressand, we use annual exchange rate volatilities, the estimated standard deviation of the first-difference in the natural logarithm of the monthly exchange rate (using the IFS end-of-month exchange rate series "ae"). We use non-overlapping *monthly* data to arrive at a single estimate for *annual* exchange rate volatility. We are left with a panel of annual data (spanning year and exchange rates).

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exchange rate target zone in our model is stronger than in Krugman's (1991) model, where the exchange rate is stabilized by the promise of interventions that have to be fulfilled in equilibrium.

[22]Indeed, dis-aggregated data on trading activity is non-existent over any reasonable span of time (e.g., a year).

[23]Futures trading began in the middle of 1972 and a continuous data set covering the period after 1990 is not currently available to us. Some of the currencies were not traded throughout the entire period, so that we have 129 annual observations.

A simple OLS regression of exchange rate volatility on volume yields a positive slope coefficient (as predicted) which is insignificantly different from zero at conventional levels (the robust t-statistic is 1.5). However, as our model shows, exchange rate volatility and volume are simultaneously determined, making OLS an inappropriate estimator. As an instrumental variable, we use the natural logarithm of distance between the USA and the foreign country. This variable is suggested by the literature on the "gravity equation" of international trade. In our data set, distance is correlated with volume (the slope coefficient is 4) and thus is an admissible instrumental variable. When we compute IV estimates, the slope coefficient in our volatility/volume regression remains positive, and grows in both size and statistical significance; its t-statistic is 2.9. That is, greater exchange rate trading volume is associated with more exchange rate volatility, as our model predicts. This panel evidence twins well with the case study of the Tokyo foreign exchange market by Ito, Lyons and Melvin (1998) which found that extra trading was associated with higher exchange rate volatility.

The Bank for International Settlements collects data on a wider range of foreign exchange products, including spot trading and most derivatives. However, these data are broken down into only a few bilateral markets, and only for trades involving either the dollar or DM. Further, these data are currently only available for 1992 and 1995. Thus, we are unable to perform a regression analysis. Still, there is some evidence that increased volume is associated with greater exchange rate volatility. The 1996 survey shows that the vast majority of foreign exchange transactions occur between floating exchange rate regimes; only one of the top ten exchange markets was a fixed rate.[24] The 1993 survey shows that of the top thirteen foreign exchange markets, only two were for fixed exchange rate regimes.[25] Again, this evidence is consistent with our model.

There are a few other pieces of support for our approach. In their survey of market practitioners, Cheung and Wong (1998) show that most traders believe that non-fundamentals are of pervasive importance in foreign exchange markets, especially in the short run. Market practitioners also believe that increased speculation raises both volatility and liquidity. Flood and Rose

[24]Table F-4 indicates that the DM/FFr rate was in seventh place in terms of volume in April 1995

[25]Tables 2-B and 2-C shows that the DM/Pound market in sixth place in terms of volume, while the DM/FFr rate was in eleventh place

(1996) find that deviations from uncovered interest parity (often interpreted as risk premia) are much smaller under fixed exchange rate regimes than in floating rate regimes, again consistent with our model. Mark and Wu (1998) also make progress in the same area using a model which relies on noise traders. Rose (1996) finds that our model's focus on stated exchange rate policy and the violation of the "Incompatible Trinity" twins with the OECD data; Evans and Lyons (1999) show that the order flow which lies at the heart of most micro-structure models is an important determinant of exchange rate movements.

Individually, none of these pieces of evidence is convincing. Jointly, we think of them as weak corroboration of our model, and a strong encouragement, to us and other researchers, to develop new data sets. A more definitive test awaits better data.

4 Conclusion

Floating exchange rates tend to be volatile; fixed exchange rates are not. Does the volatility in floating rates get transferred to another part of the economy when rates are fixed? No. To a first approximation, countries with fixed exchange rates have less volatile exchange rates than floating countries, but macro-economies which are equally volatile.

This well-known finding is inconsistent with theories which model the exchange rate regime (or the exchange rate itself) as a manifestation of underlying macroeconomic shocks. Unsurprisingly, such theories have performed poorly when applied to the data

In this paper we have presented a micro-structural model which *can* be used to understand exchange rate volatility in floating exchange rates. Our model introduces noise traders, who create exchange rate volatility if they choose to enter the foreign exchange market in order to diversify their portfolios and buy foreign bonds. Noise traders benefit from holding foreign bonds, but pay a cost from entering foreign markets while also creating undesirable exchange rate volatility.

For a range of fundamental macroeconomic volatility, our model generates multiple equilibria; the noise traders can either be present or absent from the markets. If they are present, they generate exchange rate volatility; we think

of this as being a floating rate regime. But there is another, "fixed rate," equilibrium without noise traders and with a more stable exchange rate. With a suitable policy stance, the policy authorities can coordinate activity to this equilibrium. In fact, an appropriate exchange rate target zone can lower exchange rate volatility without any macroeconomic cost at all. Since the policy reduces exchange rate volatility by ensuring that the fixed exchange rate equilibrium is chosen, reducing exchange rate volatility is costless in our model. Exchange rate policy works by affecting the composition of the foreign exchange market, not by the traditional mechanism of subordinating monetary policy to an exchange rate target.

Our micro-structural model of exchange rate volatility is extremely stylized and unable to capture many aspects of reality. But, as we have shown, much more complicated *macroeconomic* models are even *less* capable of rationalizing the facts. Our model has not been directly validated with any empirics. Still, we think of it as a useful new theoretical starting point to investigate exchange rate volatility.

APPENDIX

This appendix derives the net benefit of entering the domestic market for noise traders (equation (27)). We first state the following lemma.

Lemma. Consider the stochastic variable $\rho = \overline{\rho} + \epsilon_1 + \epsilon_2$ where ϵ_1 and ϵ_2 are independently and normally distributed, centered on 0, of variance σ_1^2 and σ_2^2 respectively. Denote $U = -\exp(-ab\rho)$. Then:

$$\mathrm{E}\left(\max_b \mathrm{E}(U|\epsilon_1)\right) = -\sqrt{\frac{\sigma_2^2}{\sigma_1^2+\sigma_2^2}}\exp\left(-\frac{\overline{\rho}^2}{2(\sigma_1^2+\sigma_2^2)}\right) \tag{31}$$

Proof. We proceed backwards, computing first $\mathrm{E}(U|\epsilon_1)$, maximizing over b, and taking the expectation over ϵ_1. First, we make use of the identity:

$$ab\rho + \frac{\epsilon_2^2}{2\sigma_2^2} = \frac{1}{2\sigma_2^2}(a\sigma_2^2 b + \epsilon_2)^2 + ab(\overline{\rho} + \epsilon_1 - \frac{a}{2}\sigma_2^2 b). \tag{32}$$

to compute a closed-form expression for $\mathrm{E}(U|\epsilon_1)$:

$$\begin{aligned}
\mathrm{E}(U|\epsilon_1) &= -\int_{-\infty}^{+\infty} \exp(-ab\rho)\frac{1}{\sqrt{2\pi}\sigma_2}\exp\left(-\frac{\epsilon_2^2}{2\sigma_2^2}\right)d\epsilon_2 \\
&= \exp\left(-ab\left(\overline{\rho}+\epsilon_1-\frac{a}{2}\sigma_2^2 b\right)\right)\int_{-\infty}^{+\infty}\frac{1}{\sqrt{2\pi}\sigma_2}\exp\left(-\frac{(a\sigma_2^2 b+\epsilon_2)^2}{2\sigma_2^2}\right)d\epsilon_2 \\
&= \exp\left(-ab\left(\overline{\rho}+\epsilon_1-\frac{a}{2}\sigma_2^2 b\right)\right), \qquad (33)
\end{aligned}$$

as the integral on the right-hand side of the second equation is equal to unity (it is the integral of a normal density function).

Maximizing the quadratic function of b that appears in (33) then gives:

$$\max_b \mathrm{E}(U|\epsilon_1) = -\exp\left(-\frac{(\overline{\rho}+\epsilon_1)^2}{2\sigma_2^2}\right). \tag{34}$$

We then take the expectation of this expression over ϵ_1:

$$\mathrm{E}\left(\max_b E(U|\epsilon_1)\right) = \int_{-\infty}^{+\infty} \exp\left(-\frac{(\overline{\rho}+\epsilon_1)^2}{2\sigma_2^2}\right) \frac{1}{\sqrt{2\pi}\sigma_1} \exp\left(-\frac{\epsilon_1^2}{2\sigma_1^2}\right) d\epsilon_1. \quad (35)$$

Using now the decomposition:

$$\frac{(\overline{\rho}+\epsilon_1)^2}{2\sigma_2^2} + \frac{\epsilon_1^2}{2\sigma_1^2} = \frac{\overline{\rho}^2}{2(\sigma_1^2+\sigma_2^2)} + \frac{\left(\epsilon_1 + \frac{\sigma_1^2}{\sigma_1^2+\sigma_2^2}\overline{\rho}\right)^2}{2\frac{\sigma_1^2\sigma_2^2}{\sigma_1^2+\sigma_2^2}} \quad (36)$$

it is possible to compute the closed-form expression for (35), which is (31). **Q.E.D.**

Let us consider now the entry decision of noise trader j at time t. Without entry, trader j's expected utility is given by:

$$\mathrm{E}_{t-1}^j\left(U_t^j|\delta_t^j=0\right) = -\exp\left(-a(1+i)W\right). \quad (37)$$

while under entry it is given by:

$$\begin{aligned}\mathrm{E}_{t-1}^j\left(U_t^j|\delta_t^j=1\right) &= -\exp\left(-a(1+i)W+a\gamma\right) \\ &\quad \mathrm{E}_{t-1}^j\left(\max_{b_t^j} E_t^j\left(-\exp(-ab_t^j\rho_{t+1})\right)\right)\end{aligned}$$

At the time of her entry decision, noise trader j does not know what her expectation of the excess return will be after entry. However she knows that this expectation will be given by $\mathrm{E}_t^j(\rho_{t+1}) = \overline{\rho}+\nu_t$, where ν_t is normally distributed with variance σ_ν^2, and that the innovation in ρ_{t+1} at $t+1$ will be normally distributed with variance $\mathrm{Var}(e)$. In other terms, at the time of entry the excess return ρ_{t+1} is expected by the noise trader to be of the form $\overline{\rho}+\nu_t+\eta_{t+1}$ with $\eta_{t+1} \sim N(0,\mathrm{Var}(e))$. Applying the lemma then gives:

$$\begin{aligned}\mathrm{E}_{t-1}^j\left(U_t^j|\delta_t^j=1\right) &= -\exp\left(-a(1+i)W+a\gamma\right)\sqrt{\frac{\mathrm{Var}(e)}{\mathrm{Var}(\nu)+\mathrm{Var}(e)}} \\ &\quad \exp\left(-\frac{\overline{\rho}^2}{2(\mathrm{Var}(\nu)+\mathrm{Var}(e))}\right). \quad (38)\end{aligned}$$

It follows from the comparison of (37) and (38), and the identity $\mathrm{Var}(\nu) = \lambda \mathrm{Var}(e)$, that trader j's utility is higher under entry iff:

$$\sqrt{\frac{1}{1+\lambda}} \exp\left(-\frac{\overline{\rho}^2}{2(1+\lambda)\mathrm{Var}(e)} + a\gamma\right) < 1. \tag{39}$$

Taking the logarithm of this inequality then gives (26).

References

[1] Admati, A. and P. Pfleiderer (1988) "A Theory of Intraday Patterns" *Review of Financial Studies* 1, 3-40.

[2] Aliber, Robert (1976) "The Firm under Pegged and Floating Exchange Rates" *Scandinavian Journal of Economics* 79, 309-322.

[3] Bank for International Settlements (1996) *Central Bank Survey of Foreign Exchange and Derivatives Market Survey*, Basle: BIS.

[4] Baxter, Marianne and Alan C. Stockman (1989) "Business Cycles and the Exchange-Rate System" *Journal of Monetary Economics* 23, 377-400.

[5] Carlson, John A. and Carol L. Osler (1997) "Rational Speculators and Exchange Rate Volatility" unpublished manuscript, FRBNY.

[6] Cheung and Wong (1998) "A Survey of Market Practitioners' Views on Exchange Rate Dynamics" forthcoming, *Journal of International Economics.*

[7] De Long, J. Bradford, Andrei Shleifer, Lawrence H. Summers, and Robert J. Waldmann (1990) "Noise Trade Risk in Financial Markets" *Journal of Political Economy* 98-4, 703-738.

[8] Dornbusch, Rudiger (1976) "Expectations and Exchange Rate Dynamics" *Journal of Political Economy* 84, 1161-1176.

[9] Evans, Martin D. and Richard K. Lyons (1999) "Microstructure Meets Asset Pricing: Order Flow Effects in the FX Market" mimeo.

[10] Faruqee, Hamid and Lee Redding (1999) "Endogenous Liquidity and Exchange Rate Dynamics" forthcoming in the *Journal of Canadian Economics.*

[11] Flood, Robert P. and Nancy P. Marion (1996) "Speculative Attacks: Fundamentals and Self-Fulfilling Prophecies" NBER Working Paper No. 5789.

[12] Flood, Robert P. and Andrew K. Rose (1995) "Fixing Exchange Rates: A Virtual Quest for Fundamentals" *Journal of Monetary Economics* 36 3-37.

[13] Flood, Robert P. and Andrew K. Rose (1996) "Fixes: Of the Forward Discount Puzzle" *Review of Economics and Statistics.*

[14] Flood, Robert P. and Andrew K. Rose (1998) "Understanding Exchange Rate Volatility without the Contrivance of Macroeconomics" CEPR Discussion Paper No. 1944.

[15] Frankel, Jeffrey A. and Kenneth Froot (1987) "Using Survey Data to Test Standard Propositions Regarding Exchange Rate Expectations" *American Economic Review* 77-1, 133-153.

[16] Frankel, Jeffrey A. and Kenneth Froot (1990) "Chartists, Fundamentalists and the Demand for Dollars" in A.S. Courakis and M.P. Taylor (eds.) *Private Behaviour and Government Policy in Interdependent Economies* (Clarendon Press), 73-126.

[17] Frankel, Jeffrey A. and Richard A. Meese (1987) "Are Exchange Rates Excessively Variable?" *NBER Macroeconomics Annual* 2, 117-153.

[18] Frankel, Jeffrey A. and Andrew K. Rose (1995) "An Empirical Characterization of Nominal Exchange Rates" (with Jeffrey Frankel), in *The Handbook of International Economics* vol. III (edited by Grossman and Rogoff), Amsterdam: North-Holland.

[19] Friedman, Milton (1953) "The Case for Flexible Exchange Rates" in *Essays in Positive Economics* (Chicago: University Press).

[20] Hau, Harald (1998) "Competitive Entry and Endogenous Risk in the Foreign Exchange Market" *Review of Financial Studies 11*, 757-788.

[21] Ito, Takatoshi, Richard K. Lyons and Michael T. Melvin (1998) "Is There Private Information in the FX Market? The Tokyo Experiment" *Journal of Finance* 53, 1111-1130.

[22] Krugman, Paul (1991) "Target Zones and Exchange Rate Dynamics", *Quarterly Journal of Economics* 116, 669-82.

[23] Krugman, Paul (1989) *Exchange-Rate Instability* (Cambridge: MIT Press).

[24] Krugman, Paul and Marcus Miller (1993) "Why Have a Target Zone?" *Carnegie-Rochester Series on Public Policy* 38, 279-314.

[25] Lewis, Karen (1995) "Puzzles in International Financial Markets" in *The Handbook of International Economics* vol. III (edited by Grossman and Rogoff), Amsterdam: North-Holland.

[26] Mark, Nelson C. and Yangru Wu (1998) "Rethinking Deviations ¿From Uncovered Interest Parity: The Role of Covariance Risk and Noise" mimeo, Dept. of Economics, The Ohio State University.

[27] Meese, Richard A. and Kenneth Rogoff (1983) "Empirical Exchange Rate Models of the Seventies" *Journal of International Economics* 14, 3-24.

[28] Mussa, Michael M. (1979) "Empirical Regularities in the Behavior of Exchange Rates and Theories of the Foreign Exchange Market" *Carnegie-Rochester Series on Public Policy* 11, 9-58.

[29] Mussa, Michael M. (1986) "Nominal Exchange Rate Regimes and the Behavior of the Real Exchange Rate" *Carnegie-Rochester Series on Public Policy* 117-213.

[30] Obstfeld, Maurice (1995) "International Currency Experience: New Lessons and Lesson Relearned" *Brookings Papers on Economic Activity* 1, 119-220.

[31] Rose, Andrew K. (1994) "Are Exchange Rates Macroeconomic Phenomena?" *Federal Reserve Bank of San Francisco Economic Review* 1, 19-30.

[32] Rose, Andrew K. (1996) "Exchange Rate Volatility, Monetary Policy, and Capital Mobility: Empirical Evidence on the Holy Trinity" *The Journal of International Money and Finance.*

[33] Stockman, Alan C. (1983) "Real Exchange Rates under Alternative Nominal Exchange-Rate Systems" *Journal of International Money and Finance* 2-2, 147-166.

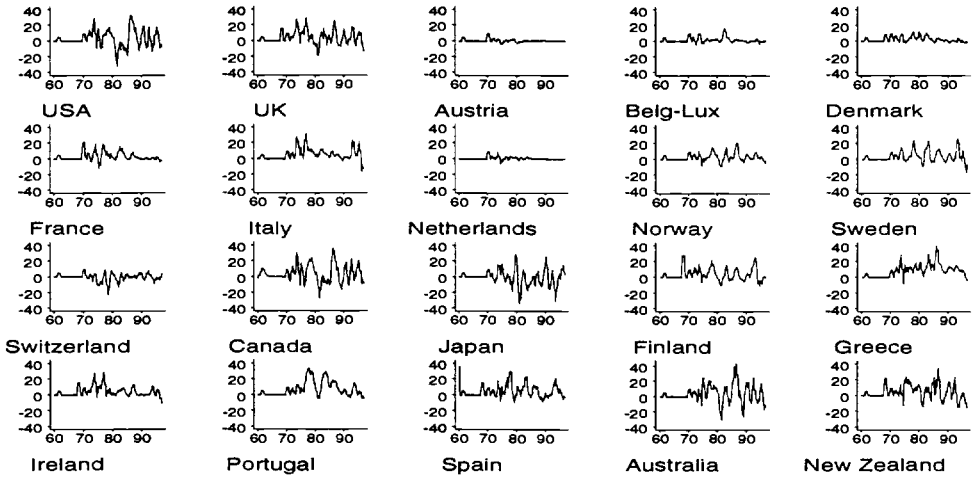

Figure 1: Time Series Evidence on Exchange Rates

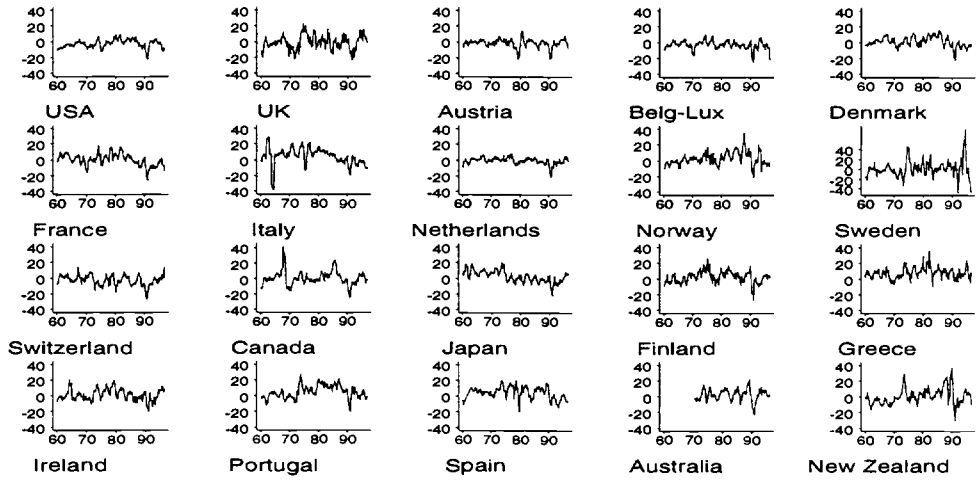

Figure 2: Time Series Evidence on Macroeconomic Fundamentals

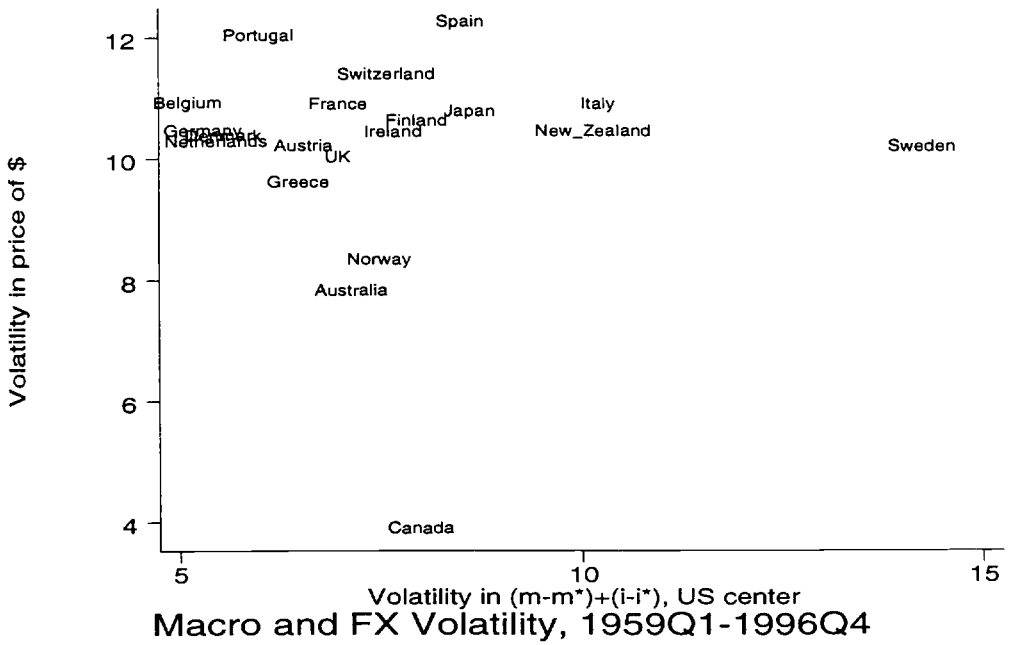

Figure 3: A Cross Section of Fundamental and Exchange Rate Volatilities

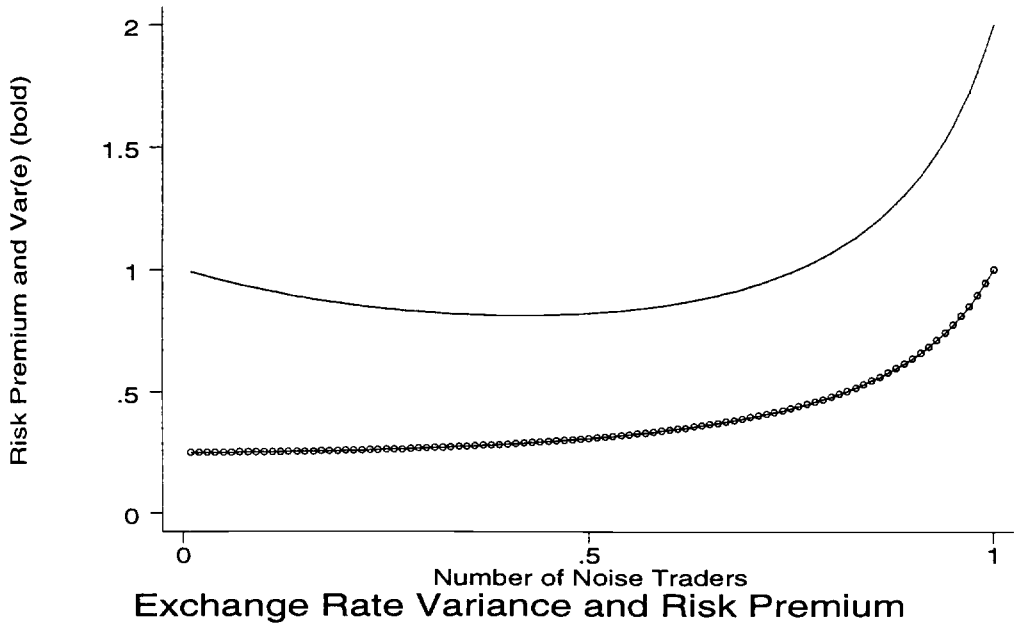

Figure 4: Exchange Rate Volatility, the Average Risk Premium, and Noise Trading

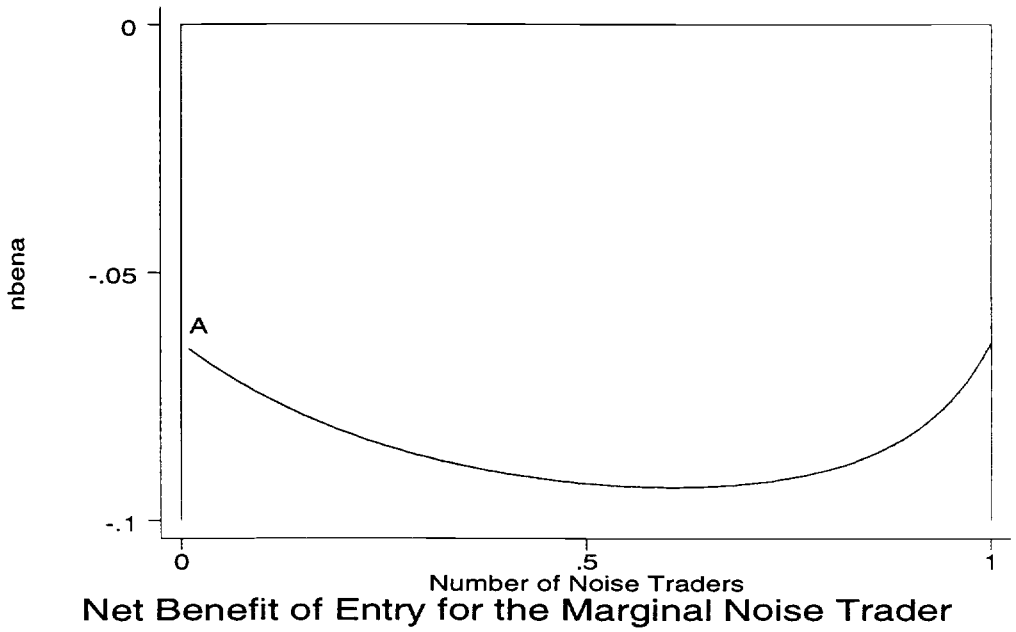

Figure 5: The (Non-)Incentives to Enter with Low Fundamental Volatility

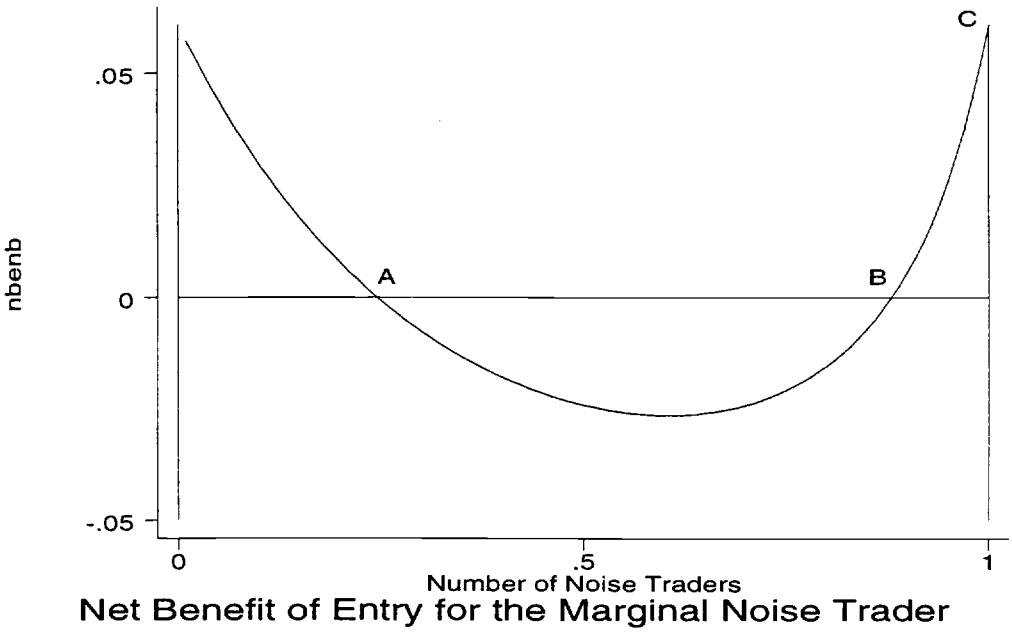

Figure 6: The Zone of Multiplicity with Moderate Fundamental Volatility

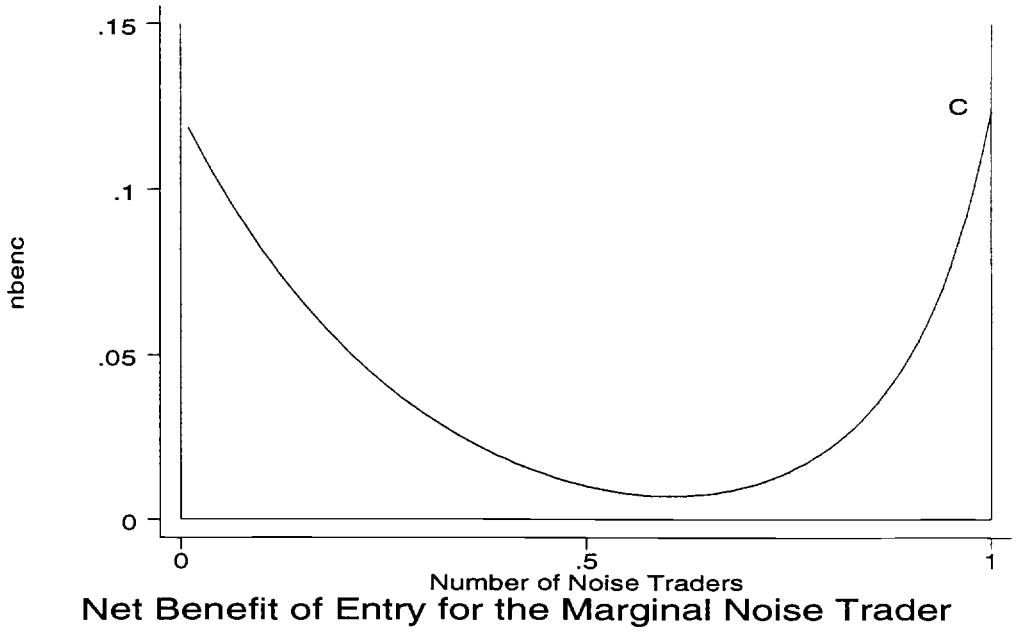

Figure 7: Incentives to Enter with Highly Volatile Fundamentals

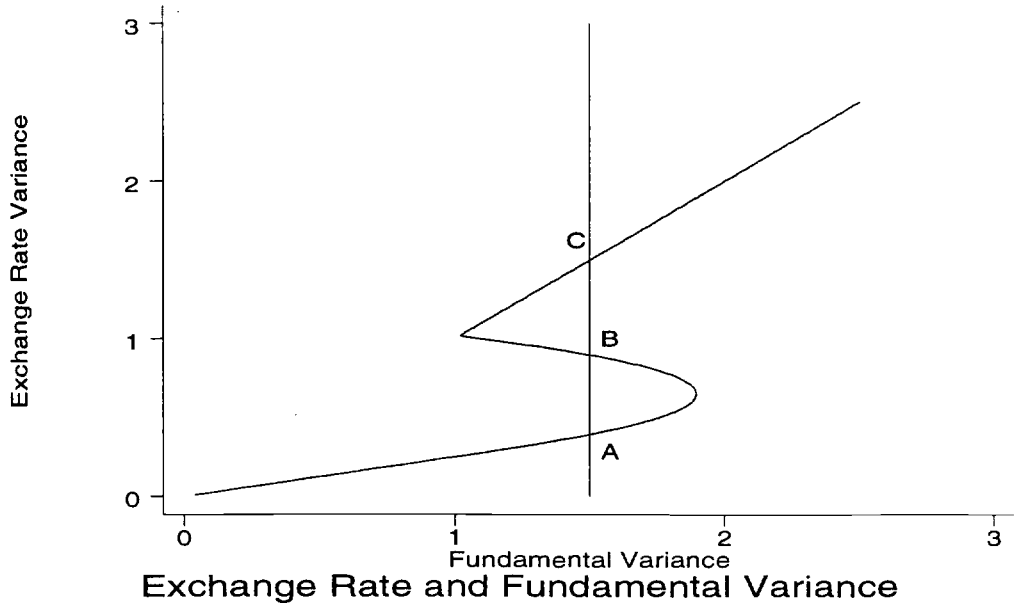

Figure 8: The Non-Linear Relationship between Exchange Rate and Fundamental Variance