

RATIONAL SPECULATORS AND EXCHANGE RATE VOLATILITY

Abstract

This paper suggests a plausible microstructural connection between rational speculative activity and exchange rate volatility. When Friedman (1953) claimed that rational speculators must smooth exchange rates, he excluded interest rate differentials from his interpretation of speculator behavior. Informed, rational speculators who consider interest differentials will magnify the exchange rate effects of interest shocks and could increase overall exchange rate volatility. This connection between speculators and volatility, which does not rely on asymmetric information, is structural because speculators affect the exchange rate's generating process. Rational speculation is stabilizing at low levels of speculative activity and destabilizing at high levels. (J.E.L. codes F31, G12. Key Words: Exchange Rate, Exchange Rate Volatility, Rational Speculation, Noise Traders)

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I. Introduction

A strong correlation seems to exist between trading volume and price volatility in major currency markets (Baillie and Bollerslev 1991, Dacorogna, et al. 1993, Ito et al. 1996). Evidence for such a correlation is also abundant for major equity and bond markets (Cornell 1981, Gallant, Rossi and Tauchen 1992). Many observers would argue that the high trading volume reflects high speculative activity which, in turn, induces the high price volatility. In fact, over 90 percent of foreign exchange market participants in Japan, Hong Kong, and Singapore believe that speculation increases volatility (Cheung and Wong 1996).

Others claim that rational speculation must reduce exchange rate volatility. The classic statement of the latter position comes from Milton Friedman (1953, p.175): "People who have argued that speculation can be destabilizing seldom realize that this is largely equivalent to saying that speculators lose money, since speculation can be destabilizing in general only if speculators sell when the currency is low in price and buy when it is high." He also points out that speculators who regularly lose money this way will be driven out of the market by speculators with more successful strategies. In sum, Friedman's position is that only rational speculators will survive in the market, and that rational speculation cannot be destabilizing.

Important policy issues hinge on the resolution of this debate. The elimination of capital controls in Europe has coincided with a renewal of intra-ERM turbulence which threatens the viability of the EMU. Viewing this as the result of heightened speculative

activity, some observers have argued for the reimposition of capital controls, if only on an as-needed basis (Eichengreen, Rose and Wyplosz 1995). Others with a similar view of speculative activity have argued for the imposition of a foreign-exchange turnover tax (Tobin 1974; Eichengreen, Tobin and Wyplosz 1994). If Friedman is right, however, a policy-induced reduction of speculative flows would increase foreign exchange volatility, worsening rather than improving the situation.

This paper shows that rational speculators can but need not increase exchange rate volatility and that, contrary to Friedman's (1953) argument, the circumstances under which they might increase volatility are plausible. An examination of Friedman's line of reasoning reveals that it does not incorporate interest rates or risk, both crucial factors for many speculators when they choose the size and direction of their positions. Changing interest differentials across countries could lead rational speculators to buy currency even when its value is "high," or to sell when its value is "low," thus "destabilizing" the exchange rate.

The result is derived in a straightforward model of the foreign exchange market with two types of traders: "speculators" and "current account traders." The speculators are rational and fully informed. Current account traders are analogous to liquidity traders in standard finance models and can be interpreted realistically in the foreign exchange context as importers and exporters of goods and services.

We find that speculators' effect on exchange rate volatility varies according to the types of shocks hitting the market, and we divide these shocks into two categories. Some shocks, such as changes in liquidity demand, do not affect speculators' preferred portfolio positions directly. An increase in speculation dampens the exchange-rate impact of these

shocks, consistent with Friedman's view. Other shocks, such as changes of interest rates or risks, do directly change speculators' preferred portfolio positions. As more speculators are introduced into the market, their total reaction to these shocks increases, inducing a rise in the exchange rate's reaction to the shock—an outcome entirely at variance with Friedman's view. These mixed effects of speculators on exchange rate volatility sort themselves out according to the level of speculative activity. At low levels of speculative activity, the Friedman effect dominates and the introduction of more speculators reduces exchange rate volatility; at high levels the reverse is true.

The results of the paper support Flood and Taylor's (1996) observation that there may be “speculative forces at work in the foreign exchange market which are not reflected in the usual menu of macroeconomic fundamentals” (p. 9). In particular, the results suggest that the fundamental determinants of exchange rate dynamics include microstructural factors such as the extent of speculative activity.

By pointing to the potential importance of microstructural factors in exchange rate dynamics, our results could potentially help explain the increase in real and nominal exchange rate volatility following the industrial world's 1973 shift to floating exchange rates. Evidence provided in Flood and Rose (1995) and Baxter and Stockman (1989) strongly suggests that this change cannot be explained by increased volatility among underlying macroeconomic variables. The results of the present paper suggest that the enormous increase in speculative activity since 1973 could provide an alternative explanation.

Our analysis also suggests a possible explanation for the strong high-frequency connections between the activity of speculators and financial price volatility (such as that

highlighted by Ito et al. 1996). French and Roll (1986) divide the possible explanations for these observed connections into three groups, one which relies on public information, one which relies on private information, and a third which relies on pricing errors. Our analysis suggests a fourth explanation, orthogonal to these original three: a rise in speculative activity could fundamentally affect financial price dynamics, even controlling for information availability and assuming rational pricing, by changing the way prices respond to information.

The conclusion that speculators can increase financial price volatility is certainly not new. Numerous examples of destabilizing speculation were developed in response to Friedman's claim. Early suggestions came from Baumol (1957), Stein (1961), and Farrell (1966). More recently, Hart and Kreps (1986) show that "speculative activity in an economy in which all agents are rational, have identical priors, and have access to identical information may destabilize prices, under any reasonable definition of stabilization" (p. 927). Likewise, Stein (1987) shows that "introducing a new group of speculators into the spot market for a commodity can destabilize prices" (p. 1124), even when speculators are fully informed and have rational expectations. Hau (1995) shows that speculators could increase exchange rate volatility if individual exchange rate expectations differ.

Though the mechanisms highlighted in these earlier papers are all plausible, many rely on a set of narrowly defined circumstances that may not be present in reality. For example, the Hart and Kreps (1986) model requires a very specific relationship between stochastic consumption behavior and signals about that behavior. Stein's (1987) model requires that the new group of speculators introduced to the market have access to an information source unavailable to the original speculators. The mechanism highlighted in the present paper, by

contrast, will always operate in foreign exchange markets. Analogous mechanisms can also be found in other financial markets. In stock and commodity markets, for example, changes in the domestic interest rates directly affect speculators' desired positions and could cause speculators to destabilize rather than stabilize prices.

Non-rational speculators could also destabilize financial prices, as shown in a group of papers including Frankel and Froot (1990) and De Long, Schleifer, Summers and Waldmann (1990). Though this paper is concerned with rational speculators, its results are not inconsistent with these important papers.

This paper does not address the welfare implications of speculative behavior. Though there is a presumption among naive observers that increased volatility reduces welfare, academics have noted repeatedly that the reverse could be true (see, for example, Stein 1987). Since the welfare of non-speculative agents is not modeled explicitly here, the paper focuses exclusively on the implications of speculative activity for exchange rate dynamics, without considering whether changes in those dynamics benefit or harm welfare.

Section II develops and solves the model. Section III analyzes the dynamics associated with specific types of shocks and Section IV shows how the degree of speculation affects the overall exchange-rate volatility. Section V considers a few extensions, and Section VI concludes.

II. The Model

Our model involves two types of agents, current account traders and rational speculators, and is driven by two types of exogenous shocks, those that affect goods and

services trade and those that affect interest differentials. Similar models are used in Osler (1995), which considers the impact of speculators' horizons on exchange rate dynamics, and Osler (1998), which considers the impact of short-term speculators on the propagation of exchange rate shocks. The inclusion of interest differentials distinguishes the model used here from these previous models. We first describe the two types of agents, and then describe the balance of payments equilibrium condition through which they interact. We finish this section by summarizing the solution to the model (the solution algorithm is presented in the appendix).

A. Types of Traders.

Current Account Traders. In the asset-pricing literature it is by now common for models to include “liquidity” traders, who buy and sell the asset in question for purposes unconnected with speculation. These agents are sometimes modeled as having demands which are linear in the level of the asset price in question plus a random disturbance term (see, for example, Dow and Gorton, 1993). In the foreign-exchange market these agents are immediately recognizable as importers and exporters, who maximize profits from trading goods and services. Though they could engage in speculation, these agents generally choose not to do so, reasoning that their expertise in this area is limited. In effect, they take potential losses from failing to speculate as an opportunity cost of pursuing their chosen line of business. We will discuss these agents as if they entirely abstain from speculating, which is not a bad approximation to their actual behavior, in aggregate. However, this interpretation is not critical: as discussed below, the model can be interpreted in a way which includes speculation by these agents.

In representing these agents we leave their profit-maximizing decision in the background, and focus on an abstract interpretation of their associated currency demand. Their demands for currency are, therefore, determined predominantly by the level of the exchange rate and by factors unconnected to the exchange rate which appear random to the rest of the market. Let e_t denote the log of the domestic price of foreign currency. Domestic importers and/or foreign exporters will buy foreign currency with domestic currency. When the foreign currency appreciates, or e_t rises, some or all of the appreciation is passed through to higher import prices (measured in domestic currency), leading to declines in both import volume and foreign currency demand. Foreign importers and/or domestic exporters supply foreign exchange, and their response to exchange rate changes depends on the extent of the pass-through and on the price elasticity of exports.

The net current-account/liquidity demand for foreign currency is defined as the difference between importers' demand and exporters' supply, or

$$CA_t = C + S e_t - S e_t . \quad (1)$$

where C and S are constant and e_t is a random shock. S is assumed to be positive, so that an appreciation of the foreign currency (higher e_t) lowers the net liquidity demand for foreign currency. The random shock is intended to summarize all factors other than the exchange rate that alter net foreign currency demand from current account traders, such as barriers to trade, price levels, and military engagements. These influences could very well be intertemporally correlated and need not be stationary. One can think of CA_t as the current account of the foreign country.¹

If the exchange rate, in the absence of any speculation, had to adjust to keep the current account equal to zero, then from equation (1),

$$e_t = \bar{e} + \varepsilon_t \quad (2)$$

where $\bar{e} \equiv C/S$ is the exchange rate that makes $CA_t = 0$ in the absence of shocks. On the assumption that the expected value of e_t is zero, we will call \bar{e} the long-run equilibrium exchange rate.²

Rational speculators. Speculators in this model represent a broad class of agents who exploit exchange-rate changes to make profits. This group includes interbank traders, foreign-exchange mutual-fund managers, and individual currency speculators. The group also includes managers of international bond funds and other portfolio managers who invest internationally. The primary characteristics of these agents are (I) they invest internationally in securities or loans and thereby incur exchange risk and (ii) they are paid according to the profits they make by investing funds which, in most cases, they do not own.

To reflect these attributes of the model's speculators it is natural to adopt what has become a convention among modelers in the theoretical asset-pricing literature: speculators have a constant absolute risk aversion utility function,

$$U_{t+1} = - \exp [- \theta p_{t+1}] \quad (3)$$

where p_{t+1} represents an individual speculator's profits and θ denotes a speculator's level of absolute risk aversion. To earn these profits the speculator takes a bet each period by establishing a position of size b_p , which is measured in units of foreign currency. The optimal bet, to be derived shortly, depends on expected profits. Actual profits are defined as follows:

for every unit of currency bet, the speculator earns the change in the log of the exchange rate, $e_{t+1} - e_t$, plus the short-term interest differential across countries:

$$\mathbf{p}_{t+1} = b_t[e_{t+1} - e_t + \mathbf{d}_t] \quad (4)$$

where $\mathbf{d}_t \equiv i_t^* - i_t$ denotes the excess of own-currency returns on foreign securities, i_t^* , over own-currency returns on domestic securities, i_t . It will be assumed that the only domestic and foreign securities available are one-period bonds. Thus the returns i_t^* and i_t are interest rates known with certainty at time t , and \mathbf{d}_t represents the interest differential. Further, we assume that speculators are not limited in the size of their position, be they short or long. (Note that our central conclusions are not driven by the fact that interest rates affect speculators but not current account traders. See Carlson and Osler, 1996.)

Under the assumption, to be examined later, that profits are distributed conditionally normally, speculators who maximize expected utility will behave as if they are maximizing the welfare function

$$W_t = E_t(\mathbf{p}_{t+1}) - (q/2)\text{Var}(\mathbf{p}_{t+1}) \quad (5)$$

where $E_t(\mathbf{p}_{t+1})$ denotes the expected level, and $\text{Var}(\mathbf{p}_{t+1})$ the variance, of a speculator's next-period profits conditional on information available at time t . The optimal bet is proportional to expected profits and inversely proportional to risk aversion and risk itself:

$$b_t = q_t [E_t(e_{t+1}) - e_t + \mathbf{d}_t] \quad (6)$$

where

$$q_t = \frac{1}{\theta \text{Var}(e_{t+1})} \quad (7)$$

$Var(e_{t+1})$ is the variance of the exchange rate conditional on information at time t . Later, when we solve explicitly for the exchange rate and for its variability, the conditional variance will be seen to depend on parameters generating the shocks. Since we are dealing with a standard utility function it is not surprising that the linear form of this bet function is also standard in the theoretical asset-pricing literature.

If there are N speculators, their desired portfolio holdings can be written:

$$Nb_t \equiv B_t \quad (8)$$

Changes in B_t can be viewed as the foreign country's capital account. A positive change ($B_t - B_{t-1} > 0$) is a capital flow from the domestic to the foreign country.³ Note that N need not be interpreted literally as the number of speculators. Instead, we can view N as a measure of total hours spent on speculative activity per period, where some of those hours could be associated with speculative activity of current account traders.

It is convenient to re-express the capital account as follows:

$$B_t = Nq_t (E_t e_{t+1} - e_t + \mathbf{d}_t) \equiv Q_t (E_t e_{t+1} - e_t + \mathbf{d}_t) \quad (9)$$

The parameter $Q_t \equiv Nq_t$ represents a measure of total speculative trading in the foreign exchange market.

B. Market Solution.

Assuming floating exchange rates without central bank intervention, the exchange rate adjusts to maintain the following balance of payments equation:

$$CA_t + B_t - B_{t-1} = 0. \quad (10)$$

A well-known but important point to note is that there must be a current-account surplus or deficit in order for speculators to make any change in their net holdings of foreign assets.

Note that this equilibrium condition requires flow equilibrium in the foreign exchange market. Models which relied on this equilibrium condition, the Mundell-Fleming model in particular, fell out of favor with the advent of asset market models in the 1970s, but the primary shortcoming of the earlier models was an absence of maximizing behavior on the part of speculative agents. This problem is not shared by the present model, however, since, as indicated by equations (6) and (7), our utility-maximizing speculators must be satisfied with their stock position in foreign exchange each period. A renewed appreciation of the importance of flow equilibrium in currency markets was forcefully advocated as early as Kouri (1981), and more recently by Lyons [1995] and Goodhart [1988]. This condition has been included in some relatively recent works (Bhattacharya and Weller [1993], Lyons [1995]). The importance of flow is further underlined by its centrality to the profit-making strategies of interbank traders.⁴

Substituting from (1) and (9) into this balance of payments equation and collecting terms, we have

$$E_t e_{t+1} - (1+S/Q_t)e_t - \frac{Q_{t-1}}{Q_t}[E_{t-1}e_t - e_{t-1}] = -[C + S\varepsilon_t + Q_t\delta_t - Q_{t-1}\delta_{t-1}]/Q_t \quad (11)$$

Assuming that N , S , \mathbf{q} , and the variances and covariances of the exogenous shocks are constant, we can find a solution in which $Var(e_{t+1})$ is constant. In that case, Q_t must also be a constant. Our procedure, with technical details shown in the appendix, will be to assume a constant Q and solve equation (11) for e_t as a function of $f_{t,\varphi}$, current shocks, and projections of future shocks. We ignore bubble solutions. With the solution for (11) we can

readily determine the unique constant conditional variance of the exchange rate and study how different values of parameters affect that variance.

To maintain our focus on the issue of whether speculation is stabilizing, we initially consider the special case in which the shocks are independent of each other and of all past shocks, and all future shocks have zero expected values. More general possibilities are examined in Section V. With these base assumptions, the exchange rate's dynamics can be written:

$$e_{t+1} = \lambda e_t + (1-\lambda)\bar{e} + (1-\lambda)\varepsilon_{t+1} + \frac{\lambda}{1-\lambda}\Delta_{t+1} \quad . \quad (12)$$

where the interest rate differential $d_t - d_{t-1}$ has been denoted D_t and represents the second source of exogenous shocks to this foreign exchange market.⁵ The variable λ is the smaller root of the characteristic equation:

$$\lambda^2 - (2+S/Q)I + 1 = 0. \quad (13)$$

It can be expressed as follows:

$$\lambda = \varphi - \sqrt{\varphi^2 - 1} \quad , \quad \varphi \equiv 1 + \frac{S}{2Q} \quad . \quad (14)$$

As shown in the appendix, there is a unique solution for Q , I , and $Var(e_t)$ as functions of N , S , q , $Var(\mathbf{e})$, and $Var(\mathbf{D})$. Since our equilibrium exchange rate generating process is linear in the shocks, it is sufficient to assume that the shocks are normally distributed—as we do henceforth—to conclude that the exchange rate itself will be normally distributed, as required earlier. Had we chosen to examine a nonlinear equilibrium, this property of normalcy might not have held.

Note that I , a positive fraction, is close to zero when Q is close to zero and approaches one as Q is very large. Since I and Q are monotonically related, and since Q is a measure of speculative activity as discussed earlier, I can be viewed as a measure of speculative activity.

III. Speculation and Market Dynamics

Before presenting an expression for the variability of the exchange rate, which we do in Section IV, it is worth pausing to gain a better understanding of exchange rate dynamics by considering the market response to each type of shock. We first consider how fully-informed rational speculators offset unanticipated transitory current-account shocks. We then show how the market reacts to unanticipated changes in the interest-rate differential.

A. Transitory Trade Shocks

Suppose at time t there is a transitory trade shock of $S\mathbf{e}_t$ and no interest-differential shock. For intuitive convenience, assume we enter the period with the exchange rate at its long-run equilibrium, speculators' outstanding positions at zero, and the interest differential at zero. In this case equation (12) becomes:

$$e_t = \bar{e} + (1-I) \mathbf{e}_t. \quad (15)$$

By way of comparison, note that the exchange rate would be $e_t = \bar{e} + \mathbf{e}_t$ in the absence of speculators. Thus the initial impact of a trade shock (\mathbf{e}) is smaller when speculators are present than when they are absent. In this sense, speculators can be said to stabilize the exchange rate in response to current-account shocks, just as described by Friedman (1953).

To understand why rational speculators temper the exchange rate's response to a transitory trade shock, imagine the first speculator to observe this market.⁶ If the speculator refrained from entering the market, s/he would rationally expect the exchange rate to fall from $\bar{e} + e_t$ back to \bar{e} in the next period. This implies a profit-making opportunity, to take advantage of which the speculator would sell foreign currency. Those very sales would put downward pressure on the exchange rate, as a result of which the exchange rate would initially rise by less than e -- say by xe , where $x < 1$.

The speculator's presence will affect not only the initial exchange rate, but also those of subsequent periods. For example, in the next period the speculator will need to repurchase the foreign exchange in order to realize profits, putting sufficient upward pressure on the exchange rate to raise it above its unconditional mean. Once again, if the speculator took no position between the second and third periods, the speculator would rationally anticipate that the exchange rate would decline to its unconditional mean. The natural choice is again to take a short position in anticipation of such a decline (though in this second round s/he will sell a smaller amount, since the anticipated exchange-rate decline is smaller). Through this process the speculator affects all future exchange rates, though to a progressively smaller degree.

In a full rational expectations equilibrium, with multiple speculators, the speculators take account of their aggregate effect on exchange rate dynamics. (It is this equilibrium that we describe with equation (12) or, in more general cases, with equation (A.12) in the appendix.) In response to a trade shock of $S\mathbf{e}$ the exchange rate initially rises by $(1-I)\mathbf{e}$. I summarizes the amount of smoothing pressure exerted by speculative activity, which is determined by the total amount of speculator sales in response to the shock. This selling

pressure depends, in turn, on the number of speculators, their risk aversion, and the exchange rate's (endogenous) volatility.

Our risk-averse speculators hold a short position in foreign currency only if they expect to be rewarded for that risk. Their risk premium can be defined as the expected excess returns on a foreign currency position. From equations (6) and (7),

$$E_t e_{t+1} - e_t + \mathbf{d}_t \equiv \text{Risk Premium}_t = b_t \mathbf{q} \text{Var}(e). \quad (16)$$

The risk premium is proportional to three factors: (1) the outstanding stock of foreign currency held per speculator at time t , b_t ; (2) speculators' risk aversion, \mathbf{q} ; (3) the exchange rate's conditional variability. The presence of all of these factors is consistent with many standard models.

If speculators are risk neutral ($\mathbf{q} = 0$), they take whatever positions are necessary to drive the risk premium close to zero. If speculators are risk averse, then the risk premium is time-varying. What causes these variations, however, is not necessarily changes in the inherent riskiness of one currency relative to another, or changes in risk aversion, our standard suspects. In addition to these factors, variations in risk premia are driven by changes in the profit opportunities facing speculators: these agents take positions whenever shocks to the foreign exchange market create opportunities for speculative profits, with the size of those positions and equilibrium risk premiums jointly determined period-by-period.

B. Interest-Rate Differential Shocks.

Now consider how the market reacts to a change in interest rates. Assume once again that, up through period $t-1$, the exchange rate was at its long-run equilibrium and the interest

differential was zero. Assuming as well that there are no trade shocks, equation (12) becomes:

$$e_t = \bar{e} + \frac{\lambda}{1-\lambda} \Delta_t . \quad (17)$$

A rise in the amount of speculative activity (higher Q and higher I), increases the exchange rate's response to the shock. Thus for interest-rate shocks, additional speculators do not play a stabilizing role. This contrasts sharply with the way speculators subdue the exchange rate's response to trade shocks, discussed earlier.

Where does this destabilizing influence come from? A simple, model-free explanation points to the fact that speculators may deviate from conventional wisdom and buy when the exchange rate is “high” or sell when it is “low”(in each case relative to its unconditional mean), when interest rate differentials suggest that there are profits to be made. For a model-specific explanation, it is helpful to begin with an understanding of the system's overall response to an interest shock. Suppose that interest differentials and speculators' positions begin at zero, and there is a positive shock $D_t > 0$, so that $\delta_t = D_t$, while trade shocks remain zero. Other things equal, the rise in foreign relative to domestic interest rates causes speculators to want to increase their holdings of foreign assets. In trying to purchase additional currency they will bid up the price, inducing a corresponding supply from current-account traders.

After the exchange rate's initial rise in response to the shock, speculators must expect a future fall in the value of foreign currency (e_t) since the long-run exchange rate in our example does not change. By taking the expected value of equation (12) at time t and re-

arranging terms we can show that the expected exchange rate decline next period is proportional to the gap between the current exchange rate and its long-run value:

$$E_t e_{t+1} - e_t = -(1-\lambda)(e_t - \bar{e}) \quad (18)$$

This expected decline is, of course, determined by speculators' continued equilibrium adjustments to the shock. According to equation (6), their desired foreign currency holdings will be $q\Delta_t$ once the exchange rate reaches long-run equilibrium and stops changing.⁷ Initially, however, they acquire only a part of that position, because the expected return on foreign assets falls short of the foreign interest rate by the amount of the foreign currency's expected depreciation. Speculators slowly raise their foreign asset position towards its long-run desired level as the exchange rate approaches its long-run equilibrium and slows its rate of change. Those same additional purchases are the force that sustains the foreign currency's short-run value above its long-run equilibrium value. The currency declines monotonically because speculators purchase a slightly smaller amount each period.

Once speculators have accumulated their new desired foreign currency positions, they must expect to be rewarded for carrying that position. The risk premium in our specific example with $\mathbf{d}_t = \Delta_t$ will be proportional to the interest differential itself:⁸

$$E_t e_{t+1} - e_t + \mathbf{d}_t = \mathbf{d}_t - I\Delta_t, \quad (19)$$

$$= (1-I)\Delta_t \quad (20)$$

Having described the exchange rate's response to an interest differential shock we can now examine how the system responds to an increase in speculative activity.

IV. Speculation and Exchange Rate Volatility

We begin this section with an intuitive look at the relationship between speculation and exchange rate volatility, and then provide a more rigorous treatment. Suppose there is a rise in N , the number of speculators, or a decline in the risk aversion of a given population of speculators. In each case, other things equal, there will be a greater speculative response to a given interest shock (λ will be higher). There will be more speculators trying to achieve a position of $q\Delta$, or, alternatively, the total desired increase in foreign currency holdings for a given population of speculators will be higher because the new desired long-run position of each speculator will be greater.

This captures intuitively the reason why a rise in speculative activity increases the exchange rate's response to an interest shock. Of course, the system's overall response is substantially more complex than suggested so far. Most importantly, the exchange rate's variance adjusts endogenously, and this in turn causes speculators to adjust their bet coefficients. Once these endogenous adjustments work themselves out, however, an exogenous rise in speculative activity ultimately leads to higher Q , higher λ , and a stronger initial exchange rate response to an interest differential shock.

To undertake a more rigorous examination of how speculative activity influences the conditional variance of the exchange rate, we first compute the conditional variance of the exchange rate based on equation (12). At time $t+1$ the only new information comes from \mathbf{e}_{t+1} and \mathbf{D}_{t+1} , so the unexpected exchange rate change will be

$$e_{t+1} - E_t e_{t+1} = (1-\lambda)\varepsilon_{t+1} + \frac{\lambda}{1-\lambda}\Delta_{t+1} \quad (21)$$

This allows us to calculate the conditional variance directly:

$$\text{Var}(e_{t+1}) = E_t[e_{t+1} - E_t e_{t+1}] = (1-\lambda)^2 \text{Var}(\varepsilon) + \frac{\lambda^2}{(1-\lambda)^2} \text{Var}(\Delta) \quad , \quad (22)$$

assuming \mathbf{e} and \mathbf{D} are uncorrelated.

From this expression and the monotonic relationship between \mathbf{I} and N mentioned earlier, we can infer a number of important aspects of the relationship between speculative activity and exchange rate volatility:

1. If only current-account shocks occur, with $\text{Var}(\mathbf{D}_{t+1}) = 0$, then the conditional variance of the exchange rate is monotonically decreasing in the amount of speculation. In the limit, as \mathbf{I} approaches one, the conditional variance goes to zero.
2. If only interest-rate shocks occur, with $\text{Var}(\mathbf{e}_{t+1}) = 0$, then the conditional variance of the exchange rate is monotonically increasing in the amount of speculation. As speculative activity rises, and \mathbf{I} approaches one, the conditional variance becomes arbitrarily large.
3. If both types of shocks occur, then, as speculative activity increases and \mathbf{I} rises from zero, the conditional variance of the exchange rate first falls, reaches a minimum at some λ^* , and then rises without limit.

V. Extensions

So far we have used just one measure of volatility and assumed that all shocks are independently and identically distributed with zero means. In this section, we introduce other

measures of volatility that have appeared in the literature. We also consider how different patterns of shocks might alter the impact of added speculation. The results indicate that variations in measures of volatility or in patterns of shocks do not change our conclusion that speculation can be destabilizing.

A. Other Measures of Volatility

De Long et al. (1990) measure volatility as the distance of the exchange rate from its "fundamental" in their three-period model. In an infinite-period model such as the one presented here, this is analogous to using the unconditional variance of the price level: $E [e_{t+1} - \bar{e}]^2$. The conditional variance we used in the prior section represents the unexpected movements in the exchange rate that makes speculation risky. The unconditional variance is a measure of the overall wanderings of the exchange rate and is the sort of statistic that many economists examine when trying to characterize market behavior.

In the two-period model of Stein (1987), price stability is measured in terms of period-2 price changes. In focusing on price changes, we can look at either the conditional or unconditional variance of the change. The unconditional variance of the change in the exchange rate $E [e_{t+1} - e_t]^2$ is a statistic that is of interest to economists when there are trends in the exchange rate and the unconditional variance of the exchange rate's level is undefined. It is often computed empirically when the "fundamental" is changing in unknown ways.

For each of these equally reasonable definitions of exchange-rate volatility, there are at least two approaches to considering whether speculation is destabilizing. Stein (1987)

essentially looks at the "marginal" effects of speculation, asking whether the introduction of one new speculator (or a group of new speculators) changes price volatility if some speculators are already active in the market. Alternatively, one might be interested in the "average" effects of speculation, that is, whether volatility is higher or lower with some speculators than with none.

In our model, with independent and identically distributed mean-zero shocks, all of these measures of volatility yield the same falling-then-rising pattern as the level of speculative activity increases. In fact, the minimum variance also occurs at the same value of I . For example, the unconditional variance of the exchange rate is shown in the appendix to be:

$$E[e_{t+1} - \bar{e}]^2 = \frac{(1-\lambda)}{(1+\lambda)} \text{Var}(\varepsilon) + \frac{\lambda^2}{(1-\lambda)^2} \frac{1}{1-\lambda^2} \text{Var}(\Delta) . \quad (23)$$

This expression is proportional to the conditional variance measure of volatility used in the balance of the text, with proportionality coefficient $1/(1-I^2)$.

B. Autocorrelated Current-Account Shocks

Most shocks that affect demand for currency are autocorrelated to some degree. A rise in real income in one country that raises demand for the exports of the other country will certainly last a while. Likewise a rise in one country's price level will tend to have a fairly lasting effect on demand for exports and currency of the other country. To capture this possibility we can modify the structure of the disturbances to the current-account sector of the model to make those disturbances autocorrelated. Specifically, suppose the disturbance,

which was originally a mean zero i.i.d. variable, is instead an AR(1) variable with a mean zero i.i.d. disturbance, w_t :

$$\mathbf{e}_t = \mathbf{r}\mathbf{e}_{t-1} + \mathbf{w}_t \quad (24)$$

where $0 < \mathbf{r} < 1$. In that case, the exchange rate's conditional variance can be shown to be:

$$E_t[e_{t+1} - E_t e_{t+1}]^2 = \frac{(1-\lambda)^2}{(1-\rho\lambda)^2} Var(\omega) + \frac{\lambda^2}{(1-\lambda)^2} Var(\Delta) \quad (25)$$

When $\mathbf{r} = 0$, this reduces to the conditional variance in of the basic model, presented as (22). Higher values of \mathbf{r} increase the coefficient on \mathbf{w}_{t+1} and hence increase variability attributable to current account shocks. This is because when a shock occurs, the market realizes that the shock's direct influence on the exchange rate will last long into the future, not just one period.

The pattern of exchange rate volatility falling and then rising as speculation increases remains unchanged. The variability attributable to current-account shocks approaches a lower bound of zero while the variability attributable to interest-rate shocks becomes arbitrarily large. This pattern is true of other measures of volatility as well because, at higher values of I , the rising impact of the interest-rate shocks always eventually dominates.

C. Mean-Reverting Interest Rates

Our original specification assumed that the interest-rate differential has a unit root. While this is consistent with some empirical analyses, it would seem worthwhile nonetheless to check the implications of relaxing this assumption. Specifically, assume instead that the

interest rate differential follows a stationary AR(1) process with first-order autocorrelation coefficient α and mean-zero i.i.d. disturbance \mathbf{h}_t :

$$\mathbf{d}_t = \mathbf{a} \mathbf{d}_{t-1} + \mathbf{h}_t \quad (26)$$

with $0 < \mathbf{a} < 1$. If the current-account shocks are again assumed to be i.i.d. with zero mean, the exchange rate now has the following solution:

$$e_{t+1} = \lambda e_t + (1-\lambda)\bar{e} + (1-\lambda)\varepsilon_{t+1} + \frac{\lambda}{1-\alpha\lambda}\eta_{t+1} - \frac{\lambda(1-\alpha)}{1-\alpha\lambda}\delta_t \quad (27)$$

The exchange-rate dynamics under the random-walk hypothesis for the interest-rate differential considered earlier can be seen to hold in (27) when $\alpha = 1$. Less persistence is represented by lower values of \mathbf{a} and there are now two terms to consider, one associated with \mathbf{h}_{t+1} and a second associated with \mathbf{d}_t . To understand why the coefficient on the latter is negative, keep in mind that, with mean reversion, a high current interest-rate differential means declining differentials over the future. This, in turn, implies that speculators will be planning concurrent decreases in their holdings of foreign exchange. A smaller value of \mathbf{a} makes the effect stronger because the mean reversion occurs more rapidly.

We can use (27) to calculate the conditional variance

$$E_t[e_{t+1} - E_t e_{t+1}]^2 = (1-\lambda)^2 \text{Var}(\varepsilon) + \frac{\lambda^2}{(1-\alpha\lambda)^2} \text{Var}(\eta) \quad (28)$$

It is still true that the variance first falls and then rises as I increases. So, beyond a critical amount of speculation, increased speculative activity destabilizes exchange rates even if interest differentials are mean-reverting. (Note that, for $a < 1$, it is no longer true that the coefficient on the interest-differential shocks -- and the potential effect of speculators on exchange rate volatility -- becomes arbitrarily large as I approaches 1.)

VI. Conclusions

This paper has developed a model highlighting a plausible positive connection between rational speculative activity and exchange-rate volatility. Speculators can increase volatility because they magnify the exchange-rate influence of shocks to which they respond directly. This class of shocks, illustrated in the model by changes in interest differentials, would also include changes in taxes and transaction costs, changes in perceived risk, or changes in risk aversion.

Speculators do not magnify the exchange-rate effects of all shocks: on the contrary, they tend to smooth the effects of shocks which do not directly affect their desired positions, such as shocks to international trade. When these are the only shocks, speculators' behavior will correspond directly to that describe by Friedman in considering the merits of flexible exchange rates: they will sell when exchange rates are high (relative to their long-run expected value) and buy when exchange rates are low, thereby smoothing the price.

Despite the varied effects of speculators on the exchange rate's response to shocks, their net effect on volatility is not ambiguous. At low levels of speculation, a rise

in speculative activity reduces exchange rate volatility. However, beyond some point, any further rise in speculation increase exchange rate volatility.

Unlike the speculation-volatility connections suggested by French and Roll (1986), the one suggested here does not rely on informational asymmetries between speculators and other agents or on irrationality. Instead, the model discussed here suggests that the presence of speculators changes the exchange rate's response to given shocks. In this sense it indicates that an increase in speculative activity can cause changes in foreign exchange market microstructure.

One implication of this research is that the dramatic rise in exchange rate volatility since the advent of floating exchange rates could be at least partly explained by a concurrent increase in currency speculation. Other possible causes of the increased exchange rate volatility, such as increased volatility of fundamentals themselves, have not succeeded in explaining the phenomenon (Flood and Rose 1995; Baxter and Stockman 1989). The possibility that speculation itself has been a source of increased exchange rate volatility since 1973 may be a worthy topic of future research.

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Notes

1. We have called these actors current-account traders, but some capital account transactions might belong here. Anyone whose currency demand is influenced by relative prices should be incorporated into this net demand. For example, decisions about direct investment may be influenced by the level of the real exchange rate.
2. This stylized interpretation of the exchange rate does not include any permanent shocks, which may strike some observers as contrary to facts. Including permanent shocks would not substantially affect our central conclusions. The exchange rate without speculators would be determined as follows: $e_t = \bar{e} + \mathbf{e}_t + \mathbf{w}_t$, where \mathbf{w}_t follows a random walk. The behavior of speculators (to be described later) would be only trivially affected by the inclusion of \mathbf{w}_t ; their average absolute bet would decline. What matters for speculators is the expected exchange rate change and the exchange rate's variability conditional on available information. A nonzero value of \mathbf{w}_t can be interpreted, in this context, as a change in the underlying equilibrium (a change in \bar{e}), which speculators will take into account in choosing their positions.
3. Here again, the distinction between current account and capital account agents is not as clear-cut as suggested by the text. It is certainly possible that expected future exchange rate movements may influence some of the currency purchases of goods and services traders. A more general interpretation of the model incorporates this possibility. Specifically, we can interpret S as a measure of the sensitivity of currency demand to relative prices, from whatever the source of such sensitivity; likewise, we can interpret Nq as a measure of the sensitivity of currency demand to expected excess returns, from whatever the source of such sensitivity.
4. This point is stressed in Lyons [1995], in discussing how traders use information on customers' market-orders. Another example: with a large stop-loss order a trader begins execution before the price actually reaches the exchange rate level specified by the order itself. The trader is counting on pressure from the order to push the exchange rate through and beyond the specified rate; in this way the trader can bring the average execution rate close to the specified rate.
5. This assumption implicitly sets interest rates as exogenous. Though reasonable for central bank intervention rates, the assumption may seem unrealistic for other rates that may matter for speculation. The results of the model are unchanged, however, if we allow interest rates to be determined partially endogenously. All that is required is that there be some shock affecting interest rates that is exogenous to the rest of the model. Monetary policy immediately comes to mind as a real-world example of this type of shock.
6. The subsequent analysis draws heavily on Osler (1998).
7. Speculators' long-run desired foreign currency holdings equal $q\Delta$, because, once the exchange rate reaches its long-run value and is no longer expected to change, Δ_t is the expected excess return on foreign currencies and q is desired holdings per unit of excess return.
8. In the limit, when speculative activity as measured by Q becomes arbitrarily large and λ converges to unity, there is no risk premium at all and the exchange rate satisfies uncovered interest parity.