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DOES THE NOMINAL EXCHANGE RATE REGIME MATTER FOR INVESTMENT?

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Abstract

This paper analyses the impact of exchange rate uncertainty upon the pattern of investment in different exchange rate regimes (very hard pegs, intermediate regimes, and floats) by means of a unified approach. The comparison of different exchange rate regimes indicates that currency volatility exerts only a small influence upon the level of investment spending. On the other hand, firms turn out to be more cautious about responding to exchange rate shocks in a credible target zone model than in a flexible exchange rate regime or in a target zone model with stochastic realignments.

JEL Classification: D81, E22, F31.

Keywords: investment, uncertainty, irreversibility, exchange rate regimes.

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Contents

1 Introduction

The merits of alternative exchange rate regimes is one of the most widely discussed topics in international monetary economics. In recent years, the benefits and costs of European economic and monetary union (EMU) have received much attention. In January 1999 the European Economic and Monetary Union (EMU) was inaugurated, and the euro, the common currency of 11 countries, was born. At the same time, the United States, Canada and Japan decided to stay with a flexible exchange rate system. In Britain, the government has called for a sensible debate about EMU. Unfortunately, for party reasons, pro-Europeans are reluctant to come out with a clear position on a single currency. So while Eurosceptics state their opposition in the clearest terms, pro-Europeans limit themselves to arguing that Britain must keep the option open because joining EMU might, not would, be good for the economy. For developing and transition countries sustainability and crisis prevention began to be viewed as key exchange rate regime criteria after the emerging market crises of 1995 – 1998. Much more attention was directed towards the "hardness" of alternative regimes and "extreme" institutional regimes (floats or hard pegs) received growing support because they are believed to be more crisis-prone.[1]

The co-existence and proliferation of exchange rate systems suggests that further attention should be given to the degree to which these regimes influence business investment.[2] Should countries wishing to encourage investment increase the flexibility of their exchange rate, or adopt a fixed exchange rate regime? One advantage of credible fixed exchange rate regimes, monetary unions or currency board systems is that (unanticipated) exchange rate uncertainty is reduced. Conventional wisdom implies that this is likely to increase investment, create jobs and raise output.[3] This paper is

[1] For this bipolar view concentrating upon "solutions" see Summers (2000). Fischer (2001) presents empirical evidence for emerging market economies and developing countries indicating that the proportion of countries with intermediate regimes has indeed declined during the period 1991 – 1999.

[2] Masson (2000) has estimated Markov transition probabilities between three states (hard pegs, floats, and intermediate regimes) for various periods and groups of countries. His evidence suggests that intermediate regimes are unlikely to disappear.

[3] According to the literature on hysteresis in trade, even transitory movements of exchange rates may lead to persistent restructuring if not deindustrialisation of economies. The opposite view is that monetary union might even make currencies more volatile permanently. For example, because trade

devoted to the analysis of that suspicion, i.e. we investigate the manner in which the investment-uncertainty link depends on a country's choice of exchange rate regime.

In the theoretical literature, a new conceptual framework has emerged for characterising the potential adverse effects of exchange rate uncertainty. Based on insights provided by Dixit (1989*a*), Dixit (1989*b*) and Dixit and Pindyck (1994), it is now argued that uncertainty about future exchange rates gives firms an incentive to postpone any investment (or disinvestment) in export (or import-substitution) capacity that would be difficult to reverse. By making such an investment immediately, an options facing firm runs the risk of incurring long-term costs if the home currency appreciates. By delaying, the firm risks sacrificing profits over the short run if the home currency depreciates, but can still choose to invest later.[4] This new conceptual framework thus provides a new rationalisation for the long-standing view that a system of fixed (or stable) exchange rates, other things being equal, is conducive to economic integration, efficient investment, and growth.

Despite its obvious real-world importance and considerable normative discussion on exchange rate policy in recent years, the applications of the real options framework to the link between exchange rate uncertainty and physical investment are still small in number and have many difficulties. This is not surprising since the development of real-option investment valuation models for different exchange rate regimes presents formidable difficulties. Krugman (1989) argues that in a world of highly uncertain and volatile exchange rates, firms have an incentive to adopt a "wait and see" attitude towards both investment and trading decisions. Darby et al. (1999) and Werner (2001) focus on flexible exchange rates and do not consider other possible regimes. The value added of our contribution is that we extend the domestically-oriented real options model to the case of alternative exchange rate regimes. This approach is, to the best of

among EMU members will be transacted in a common currency, and "international" trade will be smaller, European policymakers might pay less attention to other major currencies as they did before launching EMU. More in stability between the world's major currencies might result.

[4] Additionally, exchange rate uncertainty may induce firms to install excess capacity, spread over different countries, in order to be able quickly to switch production to low-cost locations subsequent to any exchange rate movements. This share of production capacity optimally located abroad increases as exchange rate volatility rises. This production flexibility argument has been expounded by Aizenman (1992). Kogut and Kulatilaka (1994) also consider the decisions of multinationals to shift production between countries in response to exchange rate movements.

our knowledge, new in the literature. Furthermore, the investigation of this question is important not only for intellectual curiosity but also for policy purposes because different regimes may yield quite different implications for business investment.[5]

The rest of the paper is structured as follows. Section 2 illustrates the link between exchange rate uncertainty and investment in a flexible exchange rate regime. Section 3 sketches the the exchange rate uncertainty-investment link in the original target zone framework. Section 4 develops two extensions with stochastic realignments. A summary and conclusions are in Section 5.

2 A Stylised Model of Exchange Rate Uncertainty and Investment with Perfectly Flexible Exchange Rates

Before turning to decision making on exchange rate regimes, it is useful to set out shortly the basic investment model that will be used throughout the paper. In recent years, the real options literature has been winning converts. Dixit and Pindyck (1994) discuss what has been the celebrated workhorse model of investment and uncertainty in much of the recent literature. The small open economy partial equilibrium framework is fairly stylised and consists of seven equations. We assume for simplicity that uncertainty in the model is due exclusively to the exchange rate. Firms operate on imperfectly competitive output markets, but take input prices as given. In the fashion of Abel and Eberly (1994) and (1995) we assume that firm face an isoelastic demand function[6]

$$p(t) := E(t)(p^*Y(t))^{(1-\psi)/\psi} \qquad \psi \geq 1 \tag{1}$$

[5] This emphasis is meant to supplement and not meant to eclipse or diminish the range of other important motives for investment.

[6] Their model is something of a classic now, with a number of authors having subsequently extended the framework to discuss various other problems.

where p and Y respectively denote the price and the quantity of the good sold. p^* is the constant foreign price, therefore p^*Y is the firm's revenue in foreign currency.[7] To simplify the evaluation we set $p^* \equiv 1$. ψ is an elasticity parameter that takes its minimum value of 1 under perfect competition and $E(t)$ denotes the exchange rate which is assumed to move unpredictably over time. We define the exchange rate E as the price of one foreign currency unit in terms of domestic currency. The production technology is described by the Cobb-Douglas production function

$$Y = (AL^{\alpha}K^{1-\alpha})^{\gamma} \tag{2}$$

where L, K, and A are labour, capital, and the technology parameter at time t, respectively. The parameters α and γ are the constant labour share and an index of returns to scale, respectively. Since labour is assumed to be adjustable costlessly, the profit identity equation can then be specified as

$$\begin{aligned} \Pi &= max\{pY - wL\} \\ &= max\{(AL^{\alpha}K^{1-\alpha})^{\gamma/\psi}E - wL\} \end{aligned}$$

It is convenient to define the common effect of the returns to scale and the competition parameter as $\xi := \gamma/\psi$. Maximising profits yields

$$\Pi = hE^{\eta_E}K^{\eta_K} \tag{3}$$

where

$$\eta_E := \frac{1}{1-\alpha\xi} > 1, \qquad \eta_K := \frac{(1-\alpha)\xi}{1-\alpha\xi} \leq 1,$$

and

$$h := (1-\alpha\xi)\left(\frac{\alpha\xi}{w}\right)^{\frac{\alpha\xi}{1-\alpha\xi}} A^{\frac{\xi}{1-\alpha\xi}} > 0.$$

[7] The assumption that firms produce only for foreign markets is for heuristic simplicity and not required for our results. The same potential impact of exchange rate uncertainty does exist for import-competing firms. Consider, for example, a German firm competing with an American firm in the German market. We assume that nominal variable costs are fixed in euro terms for the German firm and fixed in U.S. $ terms for the American firm. An appreciation of the Euro vis-à-vis the U.S. $ will lower the American firm's dollar costs. This would allow the American firm to partially (or totally) pass these lower dollar costs on in terms of lower dollar prices and have the German firm respond by matching the price decrease.

The law of motion for capital is

$$dK = I - \delta K \tag{4}$$

where δ is the depreciation rate. The costs of changing the stock of capital, $C(I)$, consist of two parts: the price of capital goods (b) and quadratic adjustment costs.

$$C(I) = bI + \varphi I^2 \tag{5}$$

The firm is risk-neutral and attempts to maximise its expected fundamental value in terms of domestic currency.[8]

$$V(K_0, E_0) = \max_I \int_0^\infty E\left[\Pi(K(t)) - C(I(t))\right] e^{-rt} dt \tag{6}$$

Future exchange rates are generally uncertain, and obey the following simple geometric Brownian motion process with no drift term

$$dE = \sigma E \, dz \tag{7}$$

where dz is the increment of a standard Wiener process, with $E[dz] = 0$ and $E[(dz)^2] = dt$.[9] The present value (6) satisfies the following Bellman equation:

$$rV = \max_I \left\{ hE^{\eta_e} K^{\eta_k} - C(I) + \frac{E[dV]}{dt} \right\} \tag{8}$$

Using Itô's lemma, the stochastic term $E[dV]/dt$ is given by:

$$\frac{E[dV]}{dt} = (I - \delta K)\frac{\partial V}{\partial K} + \frac{1}{2}\sigma^2 E^2 \frac{\partial^2 V}{\partial E^2}. \tag{9}$$

[8] Firms can hedge away exchange rate risk only in the short run. Despite the recent explosions of currency-related derivative markets, forward and future currency arrangements for maturities longer than one year are still relatively uncommon. Additionally, hedging is not free; a risk premium separates the forward rate from the expected future spot rate. Empirical evidence on hedging in Germany and the U.S. is available in Bodnar and Gebhardt (1998). Another well-known argument against firm risk aversion is based on the Modigliani-Miller theorem. This theorem implies that whatever the firm can do in terms of hedging activities, investors can do: if exchange risk is to be hedged, it need not be done by the firm.

[9] In other words, we do not provide a specific model of what the economic determinants of such exchange rate fluctuations are. Still, the stochastic structure we propose is flexible enough to generate realistic patterns of exchange rates. It is assumed in (7) that the floating exchange rate is only "lightly managed", i.e. interventions take only place episodically and do not follow any pre-announced and/or pre-considered strategy. This allows to differentiate the floating regime from an unannounced target zone regime.

Substituting equation (9) back into (8) yields

$$rV = \max_I \left\{ hE^{\eta_e}K^{\eta_k} - C(I) + (I - \delta K)\frac{\partial V}{\partial K} + \frac{1}{2}\sigma^2 E^2 \frac{\partial^2 V}{\partial E^2} \right\}. \quad (10)$$

With the adjustment cost function the terms to be maximized in equation (10) are $-bI - \varphi I^2 + Iq$ with the first order condition $-b - 2\varphi I + q = 0$. After a little algebra, optimal investment is given by

$$I^* = \frac{q-b}{2\varphi} \quad (11)$$

where $q := \frac{\partial V}{\partial K}$ is Tobin's marginal q and the subscript $(^*)$ stands for optimal investment. Inserting I^* we write equation (10)

$$rV = hE^{\eta_e}K^{\eta_k} + \frac{(q-b)^2}{4\varphi} - \delta Kq + \frac{\sigma^2}{2}E^2\frac{\partial^2 V}{\partial E^2} \quad (12)$$

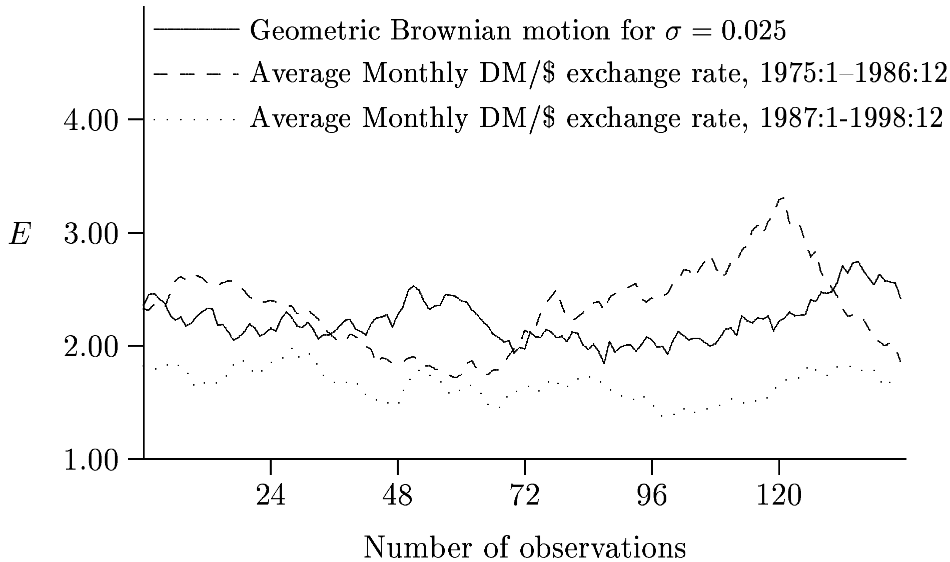
Having defined the optimal investment choice, we now turn to the question of how these optimal choices are affected by the scale of uncertainty in exchange rates. In the general case there are no closed-form solutions of the investment model, but the properties of the model can be determined numerically. The next section therefore presents numerical simulations using the so-called "Policy-Iteration Method".[10]

The simulation exercise helps visualising the features of the model, analysed analytically for $\xi = 1$ in the Appendix. Our base parameters are $b = 1$, $\varphi = 100$, $\alpha = 0.7$, $w = 0.7$, $A = 1$, $r = 0.0025$, $\delta = 0.0075$.[11] To accept this explanation as convincing, however, we would want some evidence as to why these values of parameters are plausible. Some of the parameters of the model are easily observable, others can be estimated from data available. The determination of some parameters, however, requires the use of judgement, since the data are abstract and therefore cannot directly be related to available data. In Figure 1 we review data on the DM/$ exchange rate

[10] See Howard (1960) or Kohlas (1982) for details

[11] We follow Figure 1 in that we have converted the parameters into their equivalents for a monthly model. The values chosen are best seen as reasonable approximations.

Figure 1: Actual and Generated Exchange Rates



to illustrate the coherence of the calibrated model with historical events. The results in Figure 1 indicate that the exchange rate sequences quantitatively mimick the actual DM/$ exchange rate volatility very well. The values chosen can therefore be seen as a reasonable approximation of Germany's history of foreign exchange markets having repeatedly demonstrated their ability to drive the DM/$ currency into serious medium- and longer-term misalignment. Having defined the optimal investment choice in (11), we now turn to the question of how these optimal choices are affected by the scale of uncertainty in exchange rates. The firm starts the first period with a capital stock of K_0 and the random variable E_0 is set to an equilibrium value, so that optimal investment without uncertainty equals depreciation $I_{0,\sigma=0} = \delta K_0$. Figure 2 illustrates the various investment paths which will be followed from time t_0, given different σ's and therefore brings home the importance of exchange rate uncertainty in determining investment plans.[12]

[12] We generally assume that uncertainty is of the mean-preserving spread type i.e. the simulations do not offer speculators a "one-way–option". Very hard pegs like monetary unions or currency board systems are represented by the border-line case $\sigma = 0$.

Figure 2: The Uncertainty-Investment Relationship for Flexible Exchange Rates

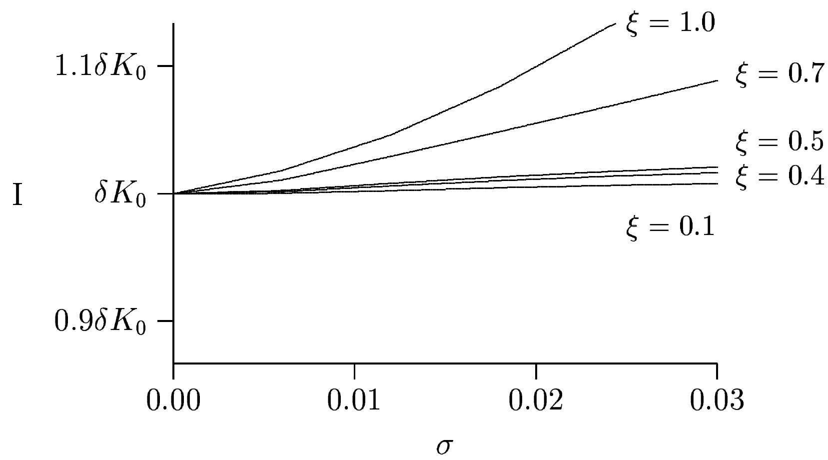


Figure 2 indicates that the effects of higher mean-preserving spreads cannot be determined unequivocally. Returning to the mainstream of our modelling approach, it is clear that the degree of competition represented by ξ influences the optimal level of the capital stock. So, to summarise, we have a series of curves relating optimal capital accumulation to different degrees of exchange rate uncertainty. A firm is likely to introduce larger increases in capacity in response to an increase in exchange uncertainty in an environment characterised by perfect competition ($\xi = 1$). Then, as the degree of imperfect competition is increased, these curves shift downwards. This positive relationship between investment and exchange rate uncertainty is at odds with what seems to occur in the real world, where the media often report the concern of firms and public authorities for the negative effects of uncertainty on project returns and, therefore, on the willingness to expand capacity. From a theoretical point of view, however, the numerical simulations confirm the well-known result of the real options literature that uncertainty yields ambiguous results – greater uncertainty may lead to more or less irreversible investment depending upon the nature of competition. An increase in uncertainty leads to an increase in investment spending under conditions of perfect competition and constant returns to scale ($\xi = 1$). Under these circumstances, the marginal return to capital is constant. According the Jensen's inequality, a mean-preserving increase in exchange rate uncertainty leads to an increase in the marginal return to capital and to a subsequent increase in investment (provided that the profit function is convex in the exchange rates). In contrast, an increase in uncertainty may lead to a different response under conditions of imperfect competition and/or decreasing returns to scale ($\xi < 1$). Under these circumstances, the marginal return to capital is a decreasing function of capacity. Increases in investment today reduce the expected marginal profitability of investment tomorrow. Consequently, the profit function's convexity with respect to the exchange rate declines, and Jensen's inequality argument loses power. The higher the degree of market power is, the more likely it is for the sign of the investment-uncertainty relationship to turn out negative.[13] The overall conclusion therefore is that it is incorrect to assume that the selection of a flexible exchange rate regime will lead to depressed investment spending due to exchange rate volatility.

3 Exchange Rate Uncertainty and Investment in a Perfectly Credible Target Zone Model

While most theoretical work has focused exclusively on either firmly fixed or perfectly flexible exchange rates, real world exchange rate regimes most often impose currency bands in order to balance credibility and flexibility. A prominent example of real world currency bands was the European exchange rate mechanism (ERM). Policy authorities in the European Monetary System (EMS) were obligated to intervene to help maintain an ECU central parity. Theory caught up with these institutional realities with the work of Krugman (1991) and Froot and Obstfeld (1991).[14] In Krugman's basic model, the exchange rate varies nonlinearly with a fundamental, usually the money supply and there exists an absolute government commitment to defend the edges of the zone. For tractability, the central bank is assumed to intervene only at the edges of the horizontal band.[15] Furthermore, the symmetric horizontal bands are regarded as being perfectly

[13] See Caballero (1991) and DeGrauwe (2000), pp. 61-63.

[14] Rose (1996) has shown that a band has a pronounced effect in limiting exchange rate variability.

[15] In the EMS system, the bands were initially $\pm 2.25\%$. In September 1992 the bands were widened to $\pm 15.00\%$ for most countries. Bartolini and Prati (1997, 1998) have recently suggested an inter-

credible; the central parity is never changed.[16] One feature of exchange rate uncertainty characterised by Brownian motions is that they tend wander far away from their starting points driving currencies into serious medium- and long-term misalignment. In order to model fixed exchange rate systems we have therefore used a mean-reverting process. The simplest mean-reverting process – also known as the Ornstein-Uhlenbeck process – is given by[17]

$$dE = \eta(\bar{E} - E)E\ dt + \sigma E\ dz \tag{13}$$

where η measures the speed of reversion, and $\bar{E}$ is the central parity, i.e. the level to which E tends to revert.

Note that the expected change in E depends upon the difference $(\bar{E}-E)$. If the current exchange rate is E_0 and E follows (13), then the expected percentage rate of change in E is

$$E\left[\frac{dE/dt}{E}\right] = \eta(\bar{E} - E_0) \tag{14}$$

and the variance for an infinitesimally small interval dt is given by

$$E[dE] = E_0^2\sigma^2 dt \tag{15}$$

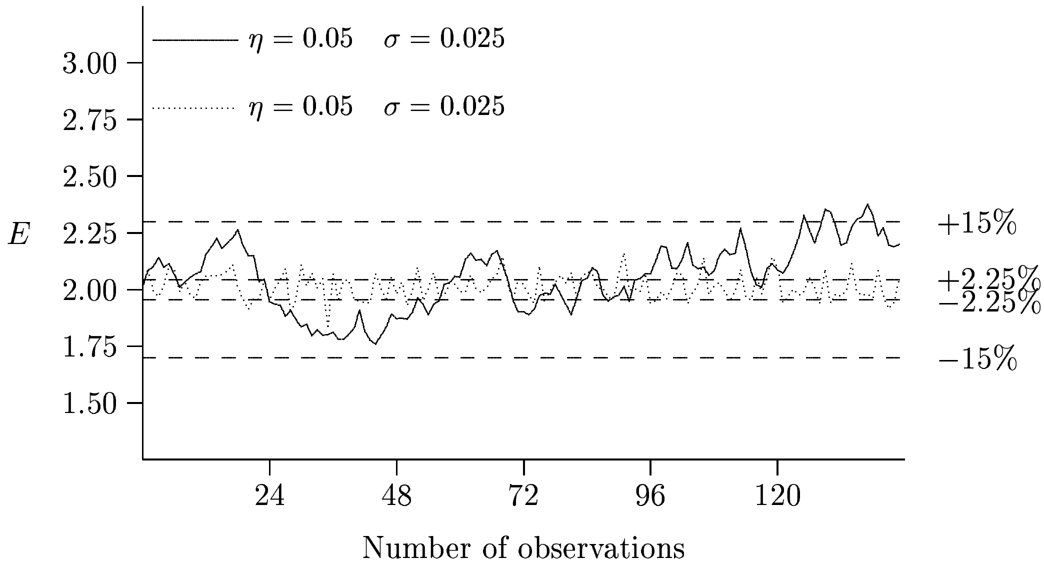
Figure 3 presents simulated Ornstein-Uhlenbeck processes for different η's and $\sigma = 0.025$. The first exchange rate sequence is for $\eta = 0.9$. Note the the exchange rate approximately stays within a 2.5% band, i.e. the exchange rate makes only very small and short-lived excursions away from the central parity. Figure 3 also shows a simulated

mediate "soft" target zone regime where the government keeps the moving average or the geometric average of current and past exchange rates within a defined band. This allows the exchange rate to move outside the band in the short run, while maintaining the obligation to hold it within the band in the long run. Limitations on space preclude extensive consideration of such regimes.

[16]The model implicitly assumes that the fixed exchange rate arrangement provides commitment mechanisms that limit discretionary policies and therefore exchange rate variability. In other words, we are not considering that the endogeneity of government exchange rate decisions leads to a time consistency problem whereby governments may wish to take actions in the future that would be different from what has been originally announced.

[17]Because the credible target zone makes the exchange rate less responsive to the fundamental, this theoretical implication is sometimes called the "honeymoon effect". This is of course a shortcut to the explicit modeling of exchange rate bands, which would involve policy reaction function.

Figure 3: Generated Exchange Rates in the Perfectly Credible Target Zone Model



exchange rate sequence for $\eta = 0.05$. A cursory look indicates that in this case the exchange rate stays within a ±15% band and therefore illustrates the situation in the EMS after the 1992/93 crash. In other words, the above parameters lead to some semi-realistic numbers on exchange rate volatility. Optimal investment is again given by (11). For further insight, optimal investment expenditures of risk-neutral firms can be computed numerically for both types of bands.

According to Figure 4 firm's turn out to be more cautious about responding to shocks in exchange rates in a credible target zone model with narrow bands than in the flexible exchange rate regime for $\xi = 1$. This effect is more powerful, the greater is the mean-preserving spread. In other words, narrow bands lead to less variable investment expenditures and are therefore better at insulating investment decisions from exchange rate shocks. These simulation results may explain some recent developments in Asia. Despite the severe financial crisis of 1997 and 1998 where exchange rates were in disarray and policymakers close to panic, the Asian crisis has led to little more than a lost year and the exchange rate crash may soon be regarded as a mere blip in the ongoing

Figure 4: The Uncertainty-Investment Relationship in the Perfectly Credible Target Zone Model with $\eta = 0.9$

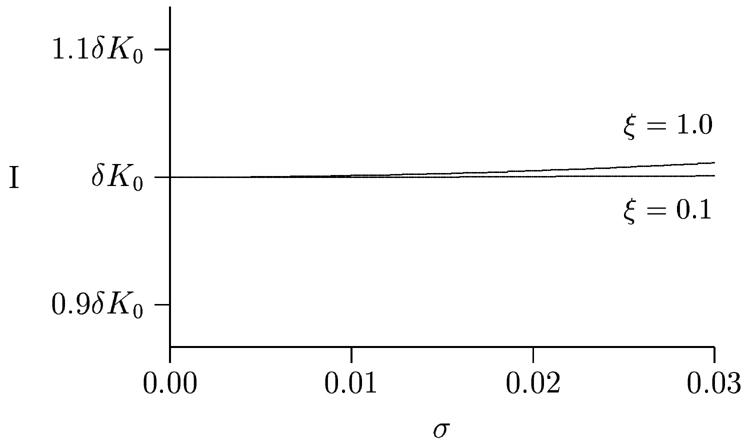
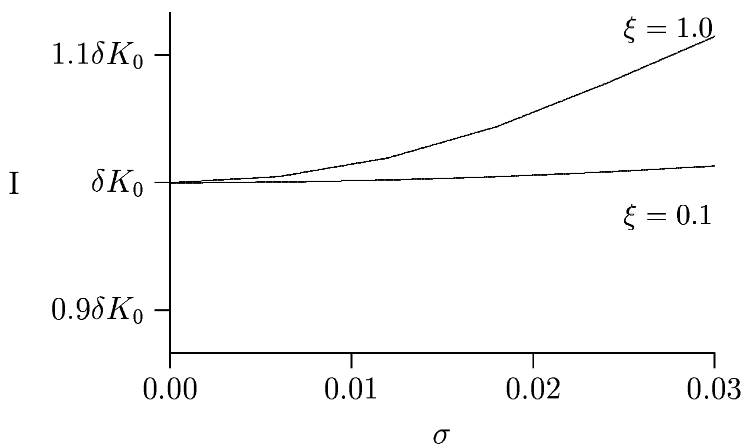


Figure 5: The Uncertainty-Investment Relationship in the Perfectly Credible Target Zone Model with $\eta = 0.05$



"Asian miracle".[18] This result suggests that European countries wishing to stabilise their economies will benefit from EMU or a credible fixed exchange rate regime with narrow bands. Now consider the regime with wider bands. Figure 5 traces the optimal investment expenditures for $\eta = 0.005$. In this case investment variability is still lower

[18] Although various economists have predicted a rebound. However, its speed and extent have taken even optimists by surprise.

than in the flexible rate regime although the bands are widened to a point where they are close to de facto floating.[19] The policy implications of this result are potentially important: investment reacts more sluggishly to exchange rate shocks when firms operate in a credible fixed exchange rate regime with narrow bands. The type of the exchange rate regime is therefore important in predicting the short run effects of exchange rate volatility. We believe this result on the effect of uncertainty on investment dynamics can also shed light on why empirical studies of mainstream investment equations often fail to perform satisfactorily: failure to include interactions between exchange rate volatility and/or uncertainty proxies and exchange rate regime dummies in empirical models may lead to unstable parameter estimates.

4 Exchange Rate Uncertainty and Investment in a Target Zone Model with Stochastic Realignments

The exposition in Section 3 was simplified by the assumption of a perfectly credible target zone. Unlike Krugman's (1991) world, however, exchange rate realignments have occurred frequently. In the case of Italy, for example, there have been 10 devaluations between 1979 and the suspension of September 17, 1992. In other words, the analytical and numerical results developed in the Section 3 made extensive use of an assumption which is obvious at variance with the complex world. Consequently, we now relax this seemingly innocuous assumption about credibility and turn to extensions of the model in Section 2 that allow for discrete, repeated realignments.[20] We first explore a simple framework with constant *exogenous* realignment risk. Then we propose a framework with a time varying *endogenous* probability of exchange rate realignments. We consider first realignment risk that is constant through time. Following Svensson (1991), we introduce a Poisson process to model fixed-but-adjustable exchange rates.

[19] The result that the variability is increasing for wider bands is not surprising because the Ornstein-Uhlenbeck process becomes a simple geometric Brownian motion as $\eta \to 0$

[20] In other words, we are modeling a regime where the the central bank targets the exchange rate and lacks credibility. See the contributions by Bertola and Caballero (1992) and Bertola and Svensson (1993). See Jeanne (1999) for an excellent survey of currency crisis models and a discussion on the taxonomy.

We have chosen this modelisation for noncredible pegs since evidence for fixed exchange rate systems shows that central parities may remain constant for a long period and, then, suddenly jump.[21]

In the extended framework the imperfectly credible central parity is allowed to switch stochastically in order to capture realignment risk. Additionally we assume that the width of the bands remains constant over time. We denote with ε_t the size of the jump of the central parity in percent if a realignment occurs at time t.[22] The fluctuations within the band are again modelled by an Ornstein-Uhlenbeck process according to Section 3. In the extended new model we therefore nest the Ornstein-Uhlenbeck process with a Poisson (jump) process. The former goes all time, the latter occurs infrequently (it jumps at realignments and is constant between realignments). One feature of this specific structure is that expected changes in the central parity are independent of the exchange rate's position in the target zone.[23] Proceeding as before, we first have to calibrate the model. The Poisson process implies that the likelihood of an appreciation or depreciation of the central parity is determined by the "arrival rate". The central parity $\bar{E}_i \in [\bar{E}_l, \bar{E}_{l+1},, \ldots, \bar{E}_{h-1}, \bar{E}_h,]$ may switch up or down to $\bar{E}_{i+1}$ and $\bar{E}_{i-1}$ with arrival rate λ according to a Poisson process. This means that the time t one has to wait for the switch event to occur is a random variable whose distribution is exponential with parameter λ:

$$F(t) := \text{prob}\{\text{Event occurs before } t\} = 1 - e^{-\lambda t} \tag{16}$$

So the probability density is

$$f(t) := F'(t) = \lambda e^{-\lambda t} \tag{17}$$

In other words, the probability that the event will occur sometime within the short interval between t_0 and $t_0 + dt$ is approximately $\lambda e^{-\lambda t} dt$. In particular, the probability

[21] In specifying the jump process in this manner we are trying to capture the idea that "good" times tend to be followed by "bad" times.

[22] In other words, we do not offer speculators a "one-way- option". This may not appear to be a very realistic assumption, but this does not cause any major problem since the only thing that matters is the possibility of a realignment. Allowing for the possibility of a richer stochastic environment with more than discrete states is a straightforward extension. A similar simplifying assumption with two states of nature has been made by Aizenman (1992).

[23] We have made this simplifying assumption for tractability

that it will occur within dt from now (when $t = 0$) is approximately λdt. In this sense λ is the probability per unit of time that the event will occur now. Moreover, the number of realignments (x) that will take place over any interval of length Δ is distributed according to the Poisson distribution

$$g(x) = \text{prob}\{\text{x events occur}\} = \frac{(\lambda\Delta)^x e^{-\lambda\Delta}}{x!} \tag{18}$$

whose expected value is the arrival rate times the length of the interval $\lambda\Delta$.

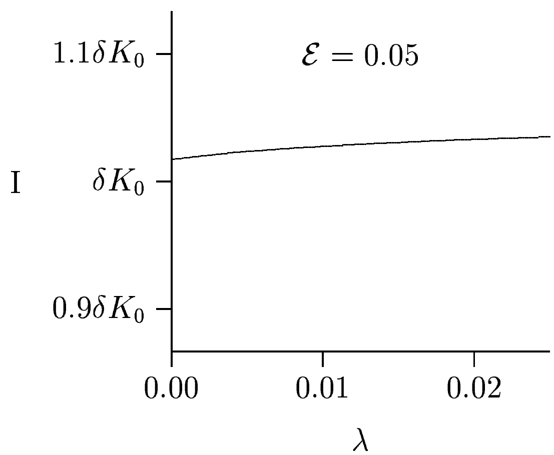
We can back out from equation (18) the model agent's beliefs about realignment risk. As a guide to calibration, Table 1 provides the probabilities that either one ($x = 1$) or three ($x = 3$) realignments will occur within 12 months ($\Delta = 12$) or 24 months ($\Delta = 24$) for the two "arrival rates" $\lambda = 0.01$ and $\lambda = 0.05$, respectively. For example, for $\lambda = 0.01$ the probability that one realignment will occur within 12 months is 10.6 percent. It is important to recognise that variations in λ allow to generate rich and realistic realignment patterns.

Table 1: Realingment Probabilities for the Poisson Process

	$\lambda = 0.01$	$\lambda = 0.05$
prob{no event in 12 months}	0.886920	0.548812
prob{1 event in 12 months}	0.106430	0.329287
prob{3 events in 12 months}	0.000255	0.019757
prob{no event in 24 months}	0.786628	0.301194
prob{1 event in 24 months}	0.188791	0.361433
prob{3 events in 24 months}	0.001812	0.086744

The interaction of the target zone model and stochastic realignments is again too complex to allow analytical results. The complexity cannot be reduced to simplicity, but it can be approached by numerical techniques in such a manner that the problem that embeds it becomes tractable, which is of the utmost importance for a whole range of exchange rate policy questions. Figure 6 to 8 portray the resulting optimal patterns of investment as a function of the underlying Ornstein-Uhlenbeck process (different η's and σ's), different assumptions about the expected percentage rate of change of the central parity $\mathcal{E}$ as well as different assumptions about the market structure, measured by ξ. Several features of the numerical solution deserve to be discussed.[24] It is inter-

Figure 6: The Uncertainty-Investment Relationship in a Target Zone Model with Exogenous Stochastic Realignments, $\xi = 0.5$, $\sigma = 0.025$, $\eta = 0.05$ and $\mathcal{E} \in [0.05; 0.20]$



esting to note that the fact that a firm merely perceives there to be the possibility of a sudden change in the central parity at some point in the future has a direct effect on the investment schedule. As is evident from Figures 6 - 8, when firms perceive realignments to be "transitory" in the sense that there exists the possibility that the present state of nature will be subject to frequent change (higher λ), then gross capital formation will be higher. Conversely, smaller values of λ, in other words lower arrival rates of realignments, result in a shrinkage of the level of investment spending. This "perverse" result should not, however, be that surprising. One way of explaining this is the following. Investment projects are considered as an option held by firms. Like any other option, the value of investing could rise with exchange rate volatility. Another feature of the results, which has been somewhat overlooked in the theoretical and empirical literature, is the interaction between time-varying λ's and gross capital

[24] All parameters remain at their baseline values unless otherwise state.

Figure 7: The Uncertainty-Investment Relationship in a Target Zone Model with Exogenous Stochastic Realignments, $\xi = 0.5$, $\sigma = 0.025$, $\mathcal{E} = 0.05$ and $\eta \in [0.05; 0.90]$

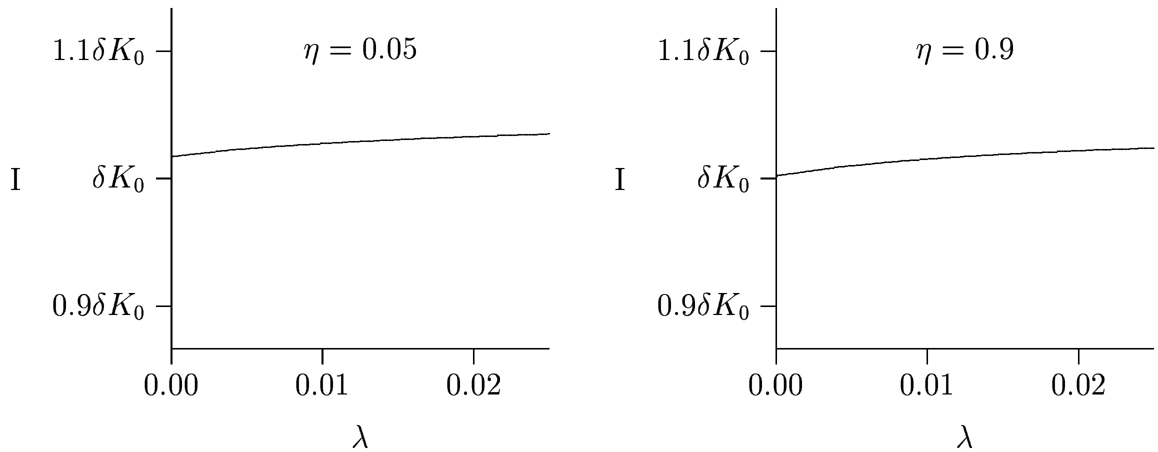
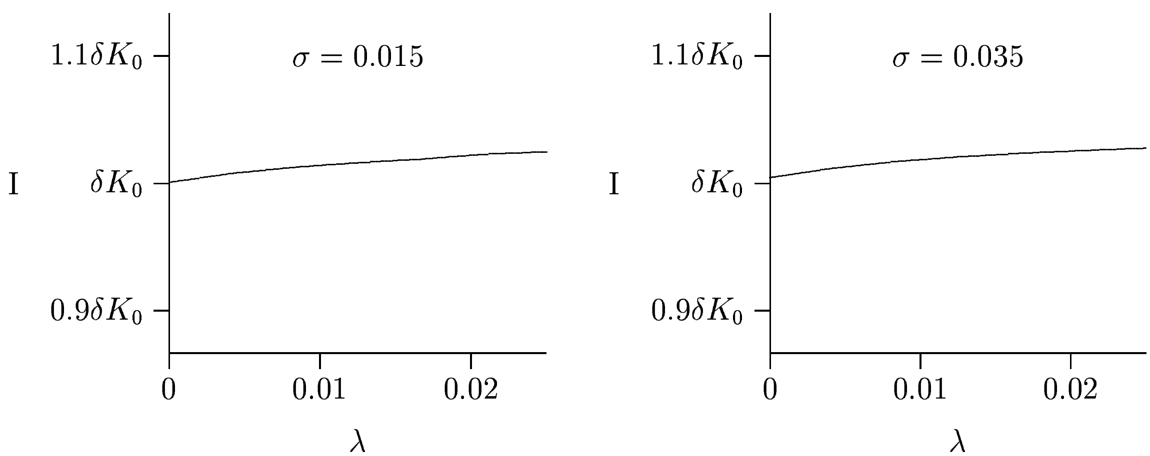


Figure 8: The Uncertainty-Investment Relationship in a Target Zone Model with Exogenous Stochastic Realignments, $\xi = 0.5$, $\mathcal{E} = 0.05$, $\eta = 0.05$ and $\sigma \in [0.015; 0.035]$



formation. The simulation results in Figure 6 and 7 indicate that time-varying jump probabilities will lead to a higher volatility of optimal investment spending, especially for larger expected jumps ($\mathcal{E} = 0.20$) and wider bands ($\eta = 0.90$). An important policy implication of our model therefore is that firms operating in a fixed exchange rate system with narrow bands and/or small expected jumps are more reluctant to increase capacity when λ is changing over time. Finally, it is interesting at this point of the analysis to compare the impact of our assumption that exchange rates evolve according to a Ornstein-Uhlenbeck-Jump process for different σ's. It is evident from Figure 8, allowing for different σ's does not lead to important upward shifts of the investment function. Finally, when comparing the simulation results in Figure 6–8 with the flexible exchange rate case in Figure 2, it turns out that the choice of a controlled exchange rate regime is not clearly associated with a climate more conducive to economic growth.

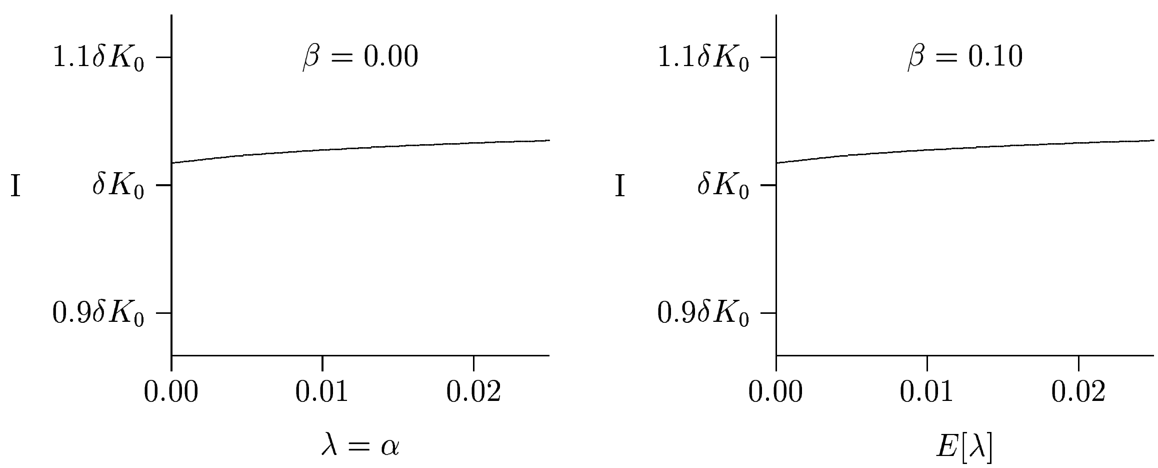
In the simulations above the realignment probability has been taken to be *exogenous* and constant throughout time. The natural generalisation of this two-state model is one in which the relignment risk is *endogenous* and time-varying. Unfortunately, modelling stochastic time-varying realignments is somewhat more tricky and the computational burden is high. In general, what is necessary is allowance for a source of exchange rate realignments. The specific model we propose assumes that the *endogenously* determined time-varying probability of a realignment λ_t depends upon the exchange rate's position within the band, i.e. we link realignment risk to the divergence of the exchange rate from parity. The jump probability can be defined in the following way:

$$\lambda_t = \alpha + \beta \log |E_t - \bar{E}|, \quad \alpha, \beta > 0 \tag{19}$$

where α and β are constants. The special case of constant realignment probability is given by $\beta = 0$, while the case $\beta > 0$ adds realism to the restrictive model presented above by assuming that the realignment probability is higher when the exchange rate is closer to the edges of its band. This formulation generates a realistic pattern of covariation between the position of the exchange rate within the band on the one hand, and the probability of realignments on the other. Proceeding as before, we ask what will be the effect on the optimal level of capital stock of increasing exchange rate uncertainty within the band. The simulations in Figure 9 use the common parameters $\eta = 0.05$,

$\xi = 0.5$, $\sigma = 0.025$ and $\alpha = 0.01$ and are therefore comparable to the first simulation in Figure 7. The endogenous switching probability follows (19) with parameters $\alpha = 0.01$ and $\beta \in [0.00, 0.10]$ which appear to be empirically reasonable. What, if anything, can the simulations tell us about investment demand? The relationship between investment and β is summarised in Figure 9. The main qualitative policy conclusion is that there is hardly any relationship between investment and β. This leads us to conjecture that the behaviour of optimal investment spending does not change in any systematic way as a result of endogenous realignment risk.[25] This, in turn, may help explain the inability of researchers to identify an effect on investment engendered by increased exchange rate volatility.

Figure 9: The Uncertainty-Investment Relationship in a Target Zone Model with Endogenous Stochastic Realignments, $\eta = 0.05$, $\xi = 0.5$, $\sigma = 0.025$, $\mathcal{E} = 0.05$, $\alpha = 0.01$ and $\beta \in [0.00; 0.10]$



This completes the discussion of exchange rate uncertainty and investment and all that remains is to provide a summary of the findings. This we do in the final Section.

[25] We have typically found such qualitative result and therefore the simulations are presented in a condensed way. The detailed results for other key parameters are available upon request from the authors.

5 Summary and Conclusions

In the introduction it was claimed that the exchange rate uncertainty investment link is an underdeveloped speciality in the real options literature although the importance of exchange rate variability has been argued in numerous contexts. Our analysis fits the logic of the real options literature and thereby constitutes an important refinement of that analysis, i.e. the models in the paper are an open economy extension of the earlier literature on investment wherein the effects of uncertainty on investment hinge on the sunk cost in capacity, on the competitive structure of the economy and on the convexity of the profit function in prices. The motivation of the paper is that since the adoption of the floating exchange rate regime in 1973 exchange rate volatility has increased tremendously. For the sake of comparison, we have therefore modelled the impact of uncertain future exchange rates upon irreversible business investment decisions in different exchange rate regimes. The analysis in the last three sections has provided some answers to that link. The basic conclusion of the simulations is that the exchange rate regimes and exchange rate uncertainty may be a "sideshow", i.e. it is not possible, from theory, to say that monetary union or credible fixed exchange rate systems with narrow bands will be associated with a climate much more conducive to economic growth. These results may explain some apparent inconsistencies in the empirical literature. Bell and Campa (1997) and Huizinga (1994) have found negative correlations between exchange rate uncertainty and investment using American and European data. In contrast, Goldberg (1993) did come up with figures showing that exchange rate volatility depressed investment in the Unites States in the 1980s, but the effect was very small and the overall results were inconclusive.[26] Bordo and Schwartz (1998) have provided a comprehensive comparison of the growth of real per capita income over a number of exchange rate regimes. The regimes covered are: the classical gold standard, 1881-1913, the inter-war period, 1919-1939, the Bretton Woods period, 1946-1970 and the recent floating rate period, 1973 to present. In summary, Bordo and Schwartz (1998) find the following: the Bretton Woods period, and particularly the

[26] She finds very little evidence of exchange rate effects on the aggregate measures of investment, however there is some evidence to suggest that it is important for disaggregate measures.

convertible subperiod from 1959-1970, exhibited the most rapid average output growth of any exchange rate regime. In contrast, however, Ghosh et al. (1995) find that there is little correlation between an adherence to fixed exchange rates and economic growth, once account is taken of the 1960s period. Finally, Baxter and Stockman (1989) have also found little hard evidence of systematic differences in the behaviour of macroeconomic aggregates under alternative exchange-rate regimes.[27]

We would like to add a caveat here. The analytical results and numerical simulations have investigated the uncertainty-investment link in a single-project partial-equilibrium framework. However, from this result it is not obvious to reach a firm conclusion regarding the effect on aggregate investment. In order to obtain inference regarding aggregate investment, a general-equilibrium setting is required. This, however, introduces an additional layer of complexity and would complicate the model enormously. Caballero and Engel (1993) and Caballero et al. (1995) have recently considered aggregation issues and have proposed frameworks to discuss the distinction between idiosyncratic and aggregate shocks, and the potentially contrasting implications of these shocks to the dynamics of aggregate variables. Their models suggest that idiosyncratic shocks tend to smooth out microeconomic rigidities, while aggregate shocks (for example, exchange rate shocks) tend to coordinate individual agents' actions. We have also not modelled the fact that firms, in reality, often confront several sources of uncertainty simulataneously. Less exchange rate volatility may then be compensated by greater volatility elsewhere, e.g. output or employment volatility. As a result, firms that operate in an environment with little exchange rate uncertainty may not on average operate in a less risky environment. Poole (1970) has considered currency uncertainty as an integral part of the whole range of risks facing firms. In our view the concepts and techniques of real options have large potentiual uses to address these questions. Given the proper tools, the dialog between economic theory and economic policy can proceed and hopefully contribute to improvements in future policy decisions.

[27] A summary of the large (and confusing) empirical literature is provided by DeGrauwe (2000), pp. 66-71.

References

Abel, A. B. (1983) "Optimal Investment under Uncertainty", *American Economic Review* **73**, 228–233.

Abel, A. B. and Eberly, J. C. (1994) "A Unified Model of Investment Under Uncertainty", *American Economic Review* **84**, 1369–1384.

Abel, A. B. and Eberly, J. C. (1995) "The Effects of Irreversibility and Uncertainty on Capital Accumulation", *NBER Working Paper No.* 5363 .

Abel, A. B. and Eberly, J. C. (1996) "Optimal Investment with Costly Reversibility", *Review of Economic Studies* **63**, 581–593.

Abel, A. B., Dixit, A. K., Eberly, J. C. and Pindyck, R. S. (1996) "Options, the Value of Capital, and Investment", *Quarterly Journal of Economics* **111**, 753–778.

Aizenman, J. (1992) "Exchange Rate Flexibility, Volatility, and Domestic and Foreign Direct Investment", *IMF Staff Papers* **39**, 890–922.

Bartolini, L. and Prati, A. (1997) "Soft Exchange Rate Bands and Speculative Attack: Theory and Evidence from the ERM Since August 1993", *IMF Working Paper* 98/156 .

Baxter, M. and Stockman, A. (1989) "Business Cycles and the Exchange Rate Regime: Some International Evidence", *Journal of Monetary Economics* **23**, 377–400.

Bell, G. and Campa, J. (1997) "Irreversible Investments and Volatile Markets: A Study of the Chemical Processing Industry", *Review of Economics and Statistics* **79**, 79–87.

Bertola, G. and Caballero, R. (1992) "Target Zones and Realignments", *American Economic Review* **82**, 520–536.

Bodnar, G. and Gebhardt, G. (1998) "Derivatives Usage in Risk Management by U.S. and German Nonfinancial Firms: A Comparative Survey", *NBER Working Paper No.* 6705 .

Bordo, M. and Schwartz, A. (1999) Policy Regimes and Economic Performance: The Historical Record, in J. Taylor and M. Woodford (eds) *Handbook of Macroeconomics*, Amsterdam (North-Holland), pp. 149–234.

Caballero, R. and Engel, E. (1993) "Heterogeneity and Output Fluctuations in a Dynamic Menu-Cost Economy", *Review of Economic Studies* **60**, 95–119.

Caballero, R., Engel, E. and Haltiwanger, J. (1995) "Plant-Level Adjustment and Aggregate Investment Dynamics", *Brookings Papers on Economic Activity* (2), 1–54.

Darby, J., Hughes Hallett, A., Ireland, J. and Piscitelli, L. (1999) "The Impact of Exchange Rate Uncertainty on the Level of Investment", *Economic Journal* **109**, C55–C67.

DeGrauwe, P. (2000) "Economics of Monetary Union".

Dixit, A. (1989*a*) "Entry and Exit under Uncertainty", *Journal of Political Economy* **97**, 620–638.

Dixit, A. (1989*b*) "Hysteresis, Import Penetration, and Exchange Rate Pass-Through", *Quarterly Journal of Economics* **26**, 309–325.

Dixit, A. K. and Pindyck, R. S. (1994) *Investment under Uncertainty*, Princeton University Press.

Froot, K. and Obstfeld, M. (1991) "Exchange Rate Dynamics Under Stochastic Regime Shifts: A Unified Approach", *Journal of International Economics* **31**, 203–229.

Goldberg, L. (1993) "Exchange Rates and Investment in the United States Industry", *Review of Economics and Statistics* **75**, 575–588.

Gosh, A.R., A. G. J. O. and Wolf, H. (1995) "Does the Nominal Exchange Rate Matter?", *IMF Working Paper No.* 95/121 .

Howard, A. R. (1960) *Dynamic Programming and Markov Processes*, Cambridge (MIT Press).

Huizinga, J. (1994) Exchange Rate Volatility, Uncertainty, and Investment: An Empirical Investigation, in L. Leiderman and A. Razin (eds) *Capital Mobility: The Impact on Consumption, Investment and Growth*, Cambridge (Cambridge University Press), pp. 185–213.

Jeanne, O. (1999) "Currency Crisis: A Perspective on Recent Theoretical Developments", *CEPR Discussion Paper No.* 2170 .

Kogut, B. and Kulatilaka, N. (1994) "Operational Flexibility, Global Manufacturing and the Option Value of a Multinational Network", *Management Science* **40**, 123–139.

Kohlas, J. (1982) *Stochastic Methods of Operations Research*, Cambridge University Press.

Krugman, P. (1991) "Target Zones and Exchange Rate Dynamics", *Quarterly Journal of Economics* **56**, 669–682.

Krugman, P. R. (1989) *Exchange-Rate Instability*, Cambridge (MIT Press).

Mussa, M. (1986) "Nominal Exchange Rate Regimes and the Behaviour of Real Exchange Rates: Evidence and Implications", *Carnegie-Rochester Conference Series on Public Policy* **25**, 117–214.

Poole, W. (1970) "Optimal Choice of Monetary Policy Instruments in a Simple Stochastic Macro Model", *Quarterly Journal of Economics* **84**, 197–216.

Rose, A. (1996) "Exchange Rate Volatility, Monetary Policy, and Capital Mobility: Empirical Evidence on the Holy Trinity", *Journal of International Money and Finance* **15**, 925–945.

Svensson, L. (1991) "The Foreign Exchange Risk Premium in a Target Zone with Devaluation Risk", *Journal of International Economics* **33**, 21–40.

Werner, T. (2001) "Die wirkung von Wechselkursvolatilitäten auf das Investitionsverhalten – Eine theoretische und empirische Analyse aus der Perspektive der Realoptionstheorie", *Kredit und Kapital* **34**, 1–27.