Exchange Rate Uncertainty and Business Sector Investment*

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Abstract: Conventional wisdom among policy makers suggests that increasing price or exchange rate variability would depress investment. Using the Dixit-Pindyck option value model, this paper argues that exchange rate variations should be split into their misalignments and prove volatility components. We can then show theoretically that there are cases where an undervaluation will increase investment expenditures, and that there are cases where those expenditures would be reduced. Similarly overvaluations may increase or decrease investment depending on certain conditions which will be industry (or economy) specific. However the important general results are: i) the persistence of a misalignment matters; ii) not allowing for separate volatility and misalignment effects results in misspecification; iii) misalignment effects may be asymmetric, in that they may differ depending on their sign; and iv) their impacts are nonlinear. This provides some communality, but beyond that misalignments/volatility have different effects in different places, depending on the industry or industrial structure. We show this on a sample of data from 4 leading OECD economies in terms of the relevant elasticities.

JEL Classification: E22, F21

I. INTRODUCTION

The conventional wisdom, that exchange rate uncertainty reduces investment[1], has recently been challenged. In a new class of models, in which investment is irreversible, Dixit and Pindyck (1994) have shown that in the face of sunk costs and uncertainty it is necessary to take into account the option value of the firm waiting to acquire more information. In a previous paper (Darby et al. (1999)) we extended this model to the case of uncertainty caused by exchange rate volatility. That kind of uncertainty makes the domestic value of foreign revenues or costs uncertain. We established in that paper, a number of sufficient conditions under which the orthodox view that increasing exchange rate uncertainty could cause investment to decrease would hold. But more importantly, we also showed that the converse result could hold - namely that, under a different set of conditions, increasing uncertainty could actually lead to an increase in investment.

One important implication of this theoretical work was that exchange rate uncertainty should be decomposed into two components: the first reflecting any systematic movements ("drift") in the exchange rate, and the second exchange rate volatility itself. We now apply that insight to our investment model (section II). The standard practice in this area has been to include only a term in volatility. To the best of our knowledge, no-one has yet included systematic changes in the exchange rate.[2] Given the non-linear nature of our theoretical model we have also experimented in our empirical work, and achieved some success, with estimating non-linear interactions between systematic exchange rate movement and volatility. This part of the analysis (Sections III and IV) contains three elements: first we have to investigate the possibility that investment responds asymmetrically to systematic positive and negative movements in the exchange rate. Second that it reacts asymmetrically to big and small misalignments; and third that interactions (nonseparability) between these influences may be important.

In Section III of the paper we discuss the actual measures of exchange rate volatility and systematic movement used in our work. We compare these to measures used elsewhere and make the case for measuring volatility around the trend value of the exchange rate. Section III also sets out our general specification of the investment equation.

Our empirical results lead to several conclusions. First, there does appear to be some evidence of a positive relationship between systematic over-valuations of the exchange rate and domestic investment. Second, we find support for the presence of asymmetric terms for systematic exchange

[1] This view is often associated with the argument that firms are risk averse and cannot completely hedge against exchange rate risk especially over the longer horizons relevant for investment: see for example, Emerson et al (1992). As we move away from these two assumptions there is less consensus about the sign of the relationship between investment and uncertainty: see Caballero (1991). A similar contrast between the conventional wisdom held by some policy makers and the dominant theoretical models is found in the literature on international trade and uncertainty; see the survey by McKenzie (1999).

[2] However Pugh et al (1998) report estimates of trade equations that contain a similar combination of exchange rate terms.

rate movements in a number of the countries examined. Third we find some evidence to suggest that large misalignments have a disproportionately greater impact on investment than small misalignments. These empirical results are presented, and compared with the existing literature, in Section IV. We also use the estimated equations to calculate a number of long run elasticties that illustrate the size and non-linear nature of the estimated interaction effects. Finally we include and evaluation of how attractive a reduction in exchange rate uncertainty would have been for investment purposes to the European governments in January 1999. In other words, the results reported here could form the basis for evaluating one of the principal motivations for the move to EMU. Of course, policy makers will appreciate that this is a (albeit, subtly) different issue from making predictions about the impact of the introduction of the euro upon investment expenditures.

II. THEORY

II. 1 The Dixit-Pindyk model for investment in a single country

Following Dixit and Pindyck (1994), consider a representative firm evaluating an investment decision which, if taken, will produce a certain amount of output, in foreign currency terms, forever. There is a sunk cost to the investment that the firm must pay once it decides to invest. The decision must be made under uncertainty, since the domestic value of that output will be uncertain. The firm's inverse demand function can be written as

$$P = YD(Q) \tag{2.1}$$

where Y is the exchange rate; and D(Q) is the firm's revenue in units of the numeraire or foreign currency, or in units of the anchor currency for European firms operating in a single market. Hence P is the output price received, measured in domestic currency units, while P_f=P/Y is the foreign currency price charged.

For the purposes of this study, we take P_f to be fixed and focus on the impact of exchange rate uncertainty alone. That means Y represents the price of domestic currency per unit of foreign currency (falling Y denotes an appreciation of the domestic currency) and D(Q) is fixed. That is, we assume that the firm is a price taker, both in foreign goods markets and in the foreign currency markets, but not necessarily in the home markets. Now suppose that the prices received follow a geometric Brownian process

$$dP = \alpha P dt + \sigma P dz \tag{2.2}$$

where dz is the increment of a Weiner process, normally distributed with zero mean and variance dt. The key features of this price distribution are: α, a measure of the systematic movement in the exchange rate; and σ, a measure of the potential volatility of the exchange rate.

Given this set up, the Dixit-Pindyck analysis proceeds as follows: if production costs are fixed in local currency, the expected discounted value of the project *per unit* of output is

$$V(P) = P/\delta$$

where

$$\delta = \mu - \alpha \, , \mu > \alpha$$

with μ the firm's discount rate and δ = the opportunity cost of waiting. Next, the value of the option to invest, or the value of waiting F(P), can be calculated using Ito's lemma and dynamic programming techniques. It turns out that

$$F(P) = BP^{\beta}$$

where B and β are constants. The projects' net present value, NPV, is then

$$NPV = V(P) - F(P) - I \tag{2.3}$$

where I is the sunk cost and the decision rule is "invest if NPV greater than zero, otherwise do not invest". The price P^* at which it just becomes profitable to exercise the option to invest is NPV equals zero. That price can be computed using the value matching condition:

$$F(P^*) = V(P^*) - I \qquad (2.4)$$

i.e. the option to wait is just as good as investing now. To that we add the smooth pasting condition:

$$F'(P^*) = V'(P^*) \qquad (2.5)$$

i.e. the value of one translates smoothly into the other. This yields

$$P^* = \frac{\beta(\mu - \alpha)I}{(\beta - 1)}$$

as the price at which investment occurs. The decision rule can therefore equivalently be expressed as "invest if P greater than P*, otherwise do not invest".

The problem with this set up is that, given sufficient uncertainty, the depreciation, maintenance and opportunity costs of idle investment may exceed the cost of closing down the activity plus the cost of restarting it. To rectify this we have to assume that each unit of output will also incur a fixed production cost C, and a sunk cost of exit E. However, the presence of sunk costs ensures that the firm will only invest if the present value of the expected revenues is higher (by an amount equal to the value of waiting) than the sunk cost of entry I. It will only disinvest if expected revenues fall below E. In other words, two threshold values for prices P_H and P_L have to be computed such that the decision rule becomes "invest if the price P rises to a value above P_H, but abandon if P falls below P_L". Between P_H and P_L, the investor should wait.

Now let $V_0(P)$ be the value of the option of waiting to invest, and $V_1(P)$ the value of the active firm - i.e. the sum of the profits expected from being active plus the value of the option to abandon. The firm retains its option to invest over the interval $(0,P_H)$, but it stays active over the interval (P_L,∞). $V_0(P)$ and $V_1(P)$ can therefore be evaluated using the same procedure as above, but applied now to the intervals $(0,P_H)$ and (P_L,∞) respectively. Once these functions have been computed, the threshold values, P_H and P_L, can be determined using the usual value matching and smooth pasting conditions:

$$V_0(P_H) = V_1(P_H) - I \qquad V_0'(P_H) = V_1'(P_H) \qquad (2.6)$$

$$V_1(P_L) = V_0(P_L) - E \qquad V_1'(P_L) = V_0'(P_L) \qquad (2.7)$$

i.e. that the value of waiting equals the value of investing; and that the value of continuing equals the value of scrapping and waiting.

II.2 The Effects of Price/Exchange Rate Uncertainty

Dixit and Pindyck show the solution to (2.6) and (2.7) is defined by the four equations below, when prices/exchange rates are given by (2.2):

$$\left.\begin{aligned} &-A_1P_H^{\beta_1} + B_2P_H^{\beta_2} + P_H/\delta - C/r = I \\ &-\beta_1A_1P_H^{\beta_1-1} + \beta_2B_2P_H^{\beta_2-1} + 1/\delta = 0 \\ &-A_1P_L^{\beta_1} + B_2P_L^{\beta_2} + P_L/\delta - C/r = -E \\ &-\beta_1A_1P_L^{\beta_1-1} + \beta_2B_2P_L^{\beta_2-1} + 1/\delta = 0 \end{aligned}\right\} \tag{2.8}$$

where i) $0<P_L<P_H$; ii) A_1 and B_2 are nonnegative endogenous variables; and iii) where

$$\begin{aligned} \beta_1 &= \tfrac{1}{2} - (\rho - \delta)/\sigma^2 + \sqrt{\left[(\rho - \delta)/\sigma^2 - \tfrac{1}{2}\right]^2 + 2\rho/\sigma^2} > 1 \\ \beta_2 &= \tfrac{1}{2} - (\rho - \delta)/\sigma^2 - \sqrt{\left[(\rho - \delta)/\sigma^2 - \tfrac{1}{2}\right]^2 + 2\rho/\sigma^2} < 0 \end{aligned} \tag{2.9}$$

In this, we assume α and σ are known at each point in time (but they don't have to be constant). Recall that δ is the opportunity cost of waiting, and ρ is the private sector rate of discount.

The impact of volatility and any systematic movement in the exchange rate, at any moment, then depends on the sign and numerical size of the partial derivatives

$$\left\{\begin{aligned} &\partial P_L / \partial\sigma \text{ and} \\ &\partial P_H / \partial\sigma;\ \text{or} \\ &\partial(P_H - P_L) / \partial\sigma \end{aligned}\right. \quad \text{and} \quad \left\{\begin{aligned} &\partial P_L / \partial\alpha \text{ and} \\ &\partial P_H / \partial\alpha;\ \text{or} \\ &\partial(P_H - P_L) / \partial\alpha \end{aligned}\right. \tag{2.10}$$

derived from (2.8) and (2.9). If increasing volatility or systematic movements were to reduce investment we would expect that

$$\frac{\partial(P_H - P_L)}{\partial\sigma} > 0 \quad \text{and} \quad \frac{\partial(P_H - P_L)}{\partial\alpha} > 0 \tag{2.11}$$

This implies that the zone of inactivity, i.e. the range of prices over which there is no new investment, will widen with increasing α and σ. In Darby et al (1999) we derive sufficient conditions for investment to fall with increased volatility, σ. We also derive the necessary conditions under which the opposite would hold. In the next section we find the corresponding (sufficient) conditions for investment to fall with increased exchange rate misalignments, α, and conversely (necessary) conditions when it might rise.

II.3 The Effect of Exchange Rate Misalignments on the Trigger Prices P_H and P_L.

In our previous paper (Darby et al, 1999) we derived the conditions for investment to fall with increasing volatility by examining the conditions under which the zone of inactivity expands, i.e. the first inequality in (2.11) holds. This we did by examining the changes in the trigger prices, and in the size of the upper tail of the distribution function of P, separately.

Following the same procedure we can sign the partial derivative for the misalignment case. The relevant expressions for the trigger prices are:

$$\frac{\partial P_H}{\partial \alpha} = \left\{ \frac{\partial \beta_1}{\partial \alpha} A_1 P_H^{\beta_1 - 1} \left(1 + \beta_1 \log P_H\right) - \frac{\partial \beta_2}{\partial \alpha} B_2 P_H^{\beta_2 - 1} \left(1 + \beta_2 \log P_H\right) + \beta_1 \frac{\partial A_1}{\partial \alpha} P_H^{\beta_1 - 1} - \beta_2 \frac{\partial B_2}{\partial \alpha} P_H^{\beta_2 - 1} - 1/\delta^2 \right\} / C_1 \qquad (2.12)$$

and

$$\frac{\partial P_L}{\partial \alpha} = \left\{ A_1 P_L^{\beta_1 - 1} \left(1 + \beta_1 \log P_L\right) \frac{\partial \beta_1}{\partial \alpha} - B_2 P_L^{\beta_2 - 1} \left(1 + \beta_2 \log P_L\right) \frac{\partial \beta_2}{\partial \alpha} + \beta_1 \frac{\partial A_1}{\partial \alpha} P_L^{\beta_1 - 1} - \beta_2 \frac{\partial \beta_2}{\partial \alpha} P_L^{\beta_2 - 1} + 1/\delta^2 \right\} / C_2 \qquad (2.13)$$

where $\frac{\partial \beta_1}{\partial \alpha} < 0, \frac{\partial \beta_2}{\partial \alpha} < 0, \text{ and } \frac{\partial A_1}{\partial \alpha} > 0 \text{ and } \frac{\partial B_2}{\partial \alpha} > 0$ follow from (2.8) and (2.9), for δ not too small and $\rho \leq \delta$. Thus one set of sufficient conditions such that $\partial(P_H\text{-}P_L)/\partial\alpha > 0$ is: that C_1 and C_2 are negative; that $1+\beta_1 \log P_H$, $1+\beta_1 \log P_L$ are positive; and that $1+\beta_2 \log P_H$, and $1+\beta_2 \log P_L$ are negative. In that case, the zone of activity widens if

$$P_H, P_L \geq e^{-1/\beta_2} > e^{-1/\beta_1} \qquad (2.14)$$

and if

$$P_H, P_L > \left[\frac{B_2 \beta_2 \left(\beta_2 - 1\right)}{A_1 \beta_1 \left(\beta_1 - 1\right)} \right]^{\frac{1}{\beta_1 - \beta_2}} \qquad (2.15)$$

These conditions are somewhat simpler than those for the pure volatility case.[3]

Necessary conditions for $\partial(P_H\text{-}P_L)/\partial\alpha$ are also simpler than before, namely $P_L > e^{-1/\beta_2}$. But that means that the first of the two sufficient conditions given in 2.14 earlier is also necessary for $\partial(P_H\text{-}P_L)/\partial\alpha > 0$. Moreover our previous paper had already shown that (2.15) is implied by (2.14), but not necessarily vice versa (Darby et al 1999). Consequently (2.14) is a necessary and sufficient condition for $\partial(P_H\text{-}P_L)/\partial\alpha > 0$, whereas (2.15) is just a sufficient condition.

The upshot of these results is that investment will certainly fall with an increasingly negative exchange rate misalignment if $P_L > e^{-1/\beta_2}$, i.e. if

[3] The results so far can be considered either as showing the impact of creating a misalignment from zero ($d\alpha > 0$ at $\alpha = 0$), or of increasing an existing misalignment $d\alpha > 0$ when $\alpha > 0$, since we considered a single period example. A continuing misalignment will of course increase these effects by cumulating them over time; see equation (2.2).

$$\frac{1}{\sigma_2}\left[\frac{\rho(\log P_L + 1) - \delta}{\log P_L}\right] > \frac{\log P_L + 1}{2(\log P_L)^2} \qquad (2.16)$$

That means we will have to consider three different cases:

Case A: $\log P_L>0$ and $\rho(\log P_L+1)>\delta$, which implies investment will fall if

$$\sigma^2<2 \log P_L\left[\rho - \frac{\delta}{1+\log P_L}\right] \qquad (2.17)$$

But if the inequality in (2.17) is reversed, then investment will rise.

Case B: If $\log P_L>0$ and $\rho(\log P_L+1)<\delta$, investment will fall if the inequality in (2.17) is reversed. But if that inequality is as stated, then investment will rise.

Case C: $\log P_L<0$, in which case investment will always rise because (2.16) is always violated.

Notice that one immediate consequence of these results is that misalignments and volatility interact. This is a consequence of the nonlinearity in investment decisions: one has to know what one factor is doing in order to predict the impact of the other. That is our first conclusion.

Notice also that the signs of these misalignment effects are reversible, all other conditions remaining the same. But the inherently nonlinear nature of all the partial derivatives obtained in the solution to (2.8) means the sizes are not reversible. Thus the change in investment from an undervaluation may be very different in size from the change obtained from an equal and opposite overvaluation. That is our second conclusion.

Consequently, it matters whether the new investment is domestic investment or foreign investment. A misalignment of the domestic currency will affect domestic investment and foreign investment in opposite ways, but to a degree that will not usually cancel out. This in contrast to the volatility case where increasing σ^2 means both domestic and foreign currencies would be affected in the same way. Hence both domestic and foreign investment, would be affected in the same way, other things equal.

II.4 Misalignments: Rationalising The Conditions For Investment To Rise Or Fall

Recall that the definition of Y implies that $\alpha>0$ represents an undervalued currency. Conversely $\alpha<0$ implies an overvalued currency. Given that, our three cases are easy to interpret:

Case C: if the price at which the project in question should be scrapped or abandoned is very low ($\log P_L<0$), then an increasingly undervalued currency ($\alpha>0$, $d\alpha>0$) would encourage greater investment in the production of goods for foreign markets - other things equal - because the domestic value of those goods will be rising while the chances of being stuck with an investment which subsequently proves to be unprofitable (because $P<P_L$,) will be getting steadily smaller. That is to say: the presence of such a misalignment produces an incentive to invest in order to diversify production into exports, conditions in the home markets remaining unchanged. Reversing this explanation also explains why investment will fall with an overvalued currency ($\alpha<0$, $d\alpha<0$) when $\log P_L<0$. But given the nonlinearity of (2.13), there is nothing to suggest that this happens at the same rate as when $\alpha>0$.

Case A: Here we have a relatively high scrapping price. But the opportunity cost of waiting, δ, is fairly small. That poses an awkward conflict between the option value part of the problem, which describes what firms would like to do in the absence of any misalignments or exchange rate uncertainty (i.e. wait rather than invest unless prices are very high); and the misalignment part of the problem which makes them want to invest in order to profit from diversifying into exports when the currency is seriously undervalued. But what determines the seriousness of that trade-off? Obviously $d\alpha>0$ when $\alpha>0$ is one part of it. But (2.17) shows that the degree of exchange rate volatility, σ^2, also plays the crucial role by altering the relative importance of the desire to wait and the desire to invest when the currency is undervalued. If σ^2 is fairly small we lose rather little by waiting, despite the increasing incentive to increase the capacity to export, because the low value of σ^2 means the current degree of misalignment can be expected to persist and the prices received are more likely to remain reasonably close to their currently misaligned values in the future. In that case the widening of the zone of inactivity will dominate most of the time; and the more "marginal" investments will be postponed until the prices get into their upper zone and stay there. The average rate of investment will therefore fall, as (2.17) predicts.

Conversely, if σ^2 were large enough, more firms would invest despite the low opportunity cost of waiting because the opportunity to exploit the current currency undervaluation won't last long and high prices cannot be expected to persist or reappear frequently. That would make firms want to speed up their marginal investments while conditions remain favourable, in order to benefit from the opportunity to diversify into exports while they can. Thus if (2.17) becomes reversed, the average rate of investment will rise - overcoming any natural tendency to wait.

Notice that in case A, as in the other two, it matters very much which side of the misalignment you are on. This is in sharp contrast to the volatility results where a rise in σ^2 implies an unambiguous rise in uncertainty whichever currency is the source of the problem. In the misalignment case it matters very much on whether the misalignment has produced an increasingly overvalued or undervalued currency at home.

Case B: This is the case where the scrapping price and opportunity cost are both relatively high. That means we reverse the argument in case A. Since it is expensive to wait, there will be no conflict between the desire to invest rather than delay and the incentive to invest in order to profit from diversifying further into exports when the currency is misaligned and undervalued. As a result, when σ^2 is large and the current misalignment cannot be expected to last for long, investment will fall with a misaligned/undervalued currency since there is little incentive to invest for diversification. Most of the time the zone of inactivity will dominate, even if waiting is costly. But, conversely, if σ^2 drops to a low level, then any undervaluation or misalignment is likely to persist or reappear. In that case the rate of investment for diversification will rise, because waiting will be relatively unattractive under persistent price deviations.

The last part of the problem is to show that the frequency with which prices exceed their upper trigger value, P_H, does not increase event though the zone of inactivity may have widened: i.e. that $\partial G(P_H)/\partial\alpha \leq 0$ when $\partial(P_H-P_L)/\partial\alpha>0$ and $G(\bullet)=1-F(\bullet)$, where $F(\bullet)$ is the distribution function associated with (2.2). A sufficient condition for that, when P follows a log normal distribution, is

$$d\alpha = \alpha_1 - \alpha_0 \leq dP_H/P_H = d\ \log P_H \tag{2.18}$$

i.e. that the upper trigger price shall increase at a rate no slower than the rate of increase in misalignment (α is defined as a factor of proportionality in (2.2)). This condition is derived in an appendix to this paper, and is evidently both necessary and sufficient for investment to fall with increasing exchange rate misalignments. Thus, the violation of (2.18) - to the extent that investment fails to fall when the zone of inactivity widens - is pretty unlikely in practice, and especially unlikely when we are concerned with small increases in an existing degree of misalignment.

II.5 The Influence Of Different Market Structures

Some authors have argued the market structure may influence the amount by which price or exchange rate volatility or misalignments can change investment expenditures. Cabellero, 1991, and Craine, 1989, are important examples. Similarly Carruth et al, 1998 - using a panel of data on British firms - have found evidence that market concentration causes investment to fall in the face of price uncertainties. Our study is silent on this issue. However, it is true that imperfect competition is likely to increase prices on average, and to increase the opportunity cost of waiting since the higher price level will encourage competitors to try to enter the market. That means that imperfectly competitive firms will probably be in case B with smaller values of σ^2, and that market concentration is therefore likely to cause investment to fall in that face of exchange rate misalignments and price uncertainties.

II.6 Finally Some Examples

In the category where investment would be harmed by an undervalued currency, we have case C where the scrapping price is very low. For example, power stations, utilities and infrastructure investments where there are few alternative uses and little scrap value. Similarly any investment with large entry costs - e.g. projects involving new technology; or "high tech" processes with large development costs; or projects involving large set-up costs to establish a position in some new market. Undervaluations therefore harm infrastructure, and "high tech" development projects.

Similarly, case B industries would also be harmed if the undervalued exchange rate were unstable. Such cases are distinguished by high scrap value, but high opportunity costs of waiting and possibly high degrees of market concentration. They include investment in financial services such as pensions. These industries have small bid/ask spreads or a large cash-in value, but volatile prices. In that case cumulative growth and traditionally high average returns means that waiting (rather than investing) carries significant penalties. Other examples would come from all those industries with high margins but somewhat speculative returns; or those which are cyclically dependent; or those dependent on patents and technical innovation, or subject to high entry costs or a shortage of skills. Increasing the degree of exchange rate stability would increase investment in these industries when the currency was undervalued, but damage it if the currency is overvalued.

By contrast, those industries whose investment is likely to be unambiguously enhanced by exchange rate stability come from case A, with a high scrap value but a low opportunity costs of waiting. This would typically include service jobs, and manufacturing industries involving low or medium levels of skills or technical sophistication. These are industries with stable future returns (rather than speculative), and where "retooling" is relatively easy as prices move and/or where movements around the cycle are unimportant.

Our fourth conclusion is therefore: the aggregate effect of exchange rate misalignments on investment will depend critically on the industrial structure of the economy. Consequently, whether investments is increased or decreased by the absence of exchange rate volatility or misalignments could go either way, ore it could be quite unimportant, depending on a particular economy's structure and the particular industry involved. That means the question of whether exchange rate uncertainty damages investment or not must be an empirical matter, not an analytic certainty. In the remaining sections of the paper we make such an assessment for 4 leading OECD countries.

III. THE EMPIRICAL FRAMEWORK

In order to make headway in evaluating the impact of exchange rate uncertainty upon the level of aggregate investment we need to make a number of modelling decisions.

III.1 Towards a Model of Investment

In our theoretical work we derived expressions for the partial derivatives of P_L and P_H with respect to α and σ. However, neither P_L or P_H are directly observable in aggregate data sets. As a result we are unable to estimate an empirical equations based directly upon the functional forms in our analytic model. Furthermore, even if we could estimate such relationships they would not be helpful in quantifying any relationship between the level of aggregate investment and exchange rate uncertainty. As Pindyck and Solimano (1993) point out, it would be necessary to have additional information on the distribution of investment projects across firms.[4] That information is just not available.

Thus, if we wish to study the links between exchange rate uncertainty and the level of investment we need to employ a less formal approach. In this paper we augment the standard empirical models of investment behaviour with measures of exchange rate uncertainty which reflect some of the implications of our theory. As a result the links between these measures and α and σ cannot always be made explicit. But we are still able to determine the sign and size of the effect of exchange rate uncertainty upon the level of investment. Moreover there are good precedents for our approach in the existing empirical literature on trade and investment in the face of exchange rate uncertainty.[5]

In addition our approach also allows us to avoid introducing explicitly all the complexities of aggregation into our empirical models. Nevertheless basing the empirical model on a theoretical structure constructed form a representative firm, rather than from a whole industry or economy, could be rather doubtful. We do it here in order to give a proper microfoundations underpinning to our empirical estimates. However, aggregation is likely to be a non-trivial issue in the presence of the trigger prices P_H and P_L. Consequently an important area for future empirical work would be to use more disaggregated data sets, for example, at the industry level.

How then do we introduce measures of exchange rate uncertainty which reflect our theoretical work into a standard model of investment? We have seen that exchange rate uncertainty can be decomposed into two components, one reflecting systematic movements in the exchange rate and the other reflecting any stochastic variations. It seems that all previous studies in the area have focussed on exchange rate volatility and fail to consider how systematic or low frequency movements in the exchange rate may affect investment.[6] That could give rise to an important mis-specification.

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[4] Pindyck and Solimano do calculate *proxies* for the upper threshold P_H in aggregate date sets by using extreme values of the marginal profitability of capital.

[5] See for example Driver and Moreton (1991) and Ferderer (1993). Our approach has also been adopted in the wider literature on investment and uncertainty arising from sources other than exchange rates.

[6] By way of a contrast note that Nucci and Pozzolo (1998) investigate the impact of exchange rate movements on their own upon investment.

We discuss our choice of measures of volatility and misalignments in the exchange rate in detail in Sections III.3 and III.4 below. For the moment we make two observations.

(i) Our measures are empirical analogues related in some complex – and, as yet, unknown – way to the underlying theoretical concepts α and σ. Since that relationship is not exact in what follows, we will use the symbols *a* and *s* to refer to the empirical analogues of α and σ.

(ii) In the theoretical model we were working with the nominal exchange rate. This makes sense in that we are modelling trigger points P_L and P_H measured in units of domestic currency, so the nominal exchange rate is required to convert foreign currency prices into a domestic currency price comparable with the trigger prices. However our empirical equations (in common with other work in the trade and in the investment area) do not explicitly include foreign currency prices. Nor do they include expressions for the domestic trigger prices. Consequently variations in either the nominal exchange rate or in the foreign currency price could influence movements in those trigger prices relative to domestic prices. In order that our equation should be capable of capturing either or both of these influences, it is necessary to use a real effective exchange. Thus our empirical measures of *a* and *s* are based upon the real exchange rate.

Our empirical specification follows Bean's (1981) work on UK manufacturing investment with the introduction of terms in *a* and *s*. In the long run investment is determined using

$$i^* = \theta_0 + \theta_1 y + \theta_2 a + \theta_3 s + \theta_4 q \qquad (3.1)$$

where i is the log of investment, y is the log of output and q is a measure of Tobin's Q. We impose the restriction that θ_1 equals unity in order to preserve the long run homogeneity between investment and output as implied by a CES production function under plausible assumptions about the long run growth of output and rate of depreciation (see Bean, 1981). We also test this restriction.

The short run dynamics combine two components: an error correction term between i^* and i and data determined dynamics in Δi, Δy, Δa, Δs and Δq. This leads to a general error correction model of the form

$$\Delta i_t = \omega_0 - \omega_1 \left(i_{t-k} - i^*_{t-k}\right) + \vartheta_1(L)\Delta i_{t-1} + \vartheta_2(L)\Delta y_t + \vartheta_3(L)\Delta a_t + \vartheta_4(L)\Delta s_t + \vartheta_5(L)\Delta q_t$$

where $\vartheta_i(L)$ are lag polynomials and i^*_{t-k} is given by (3.1).

We are aware that our theoretical model carries some implications about the existence of non-linearities in firms' decision rules that are not captured in the error correction model described above. As a result we have allowed for both systematic and volatility effects separately, as well as terms in which *a* and *s* interact. We have also tested for the existence of asymmetric reactions of investment to uncertainty for the same reason. Our final specifications reflect the combination of systematic, volatility, interaction and asymmetry terms that performed best according to the standard diagnostic tests.

III.2 The Data

The primary source of data for our work has been the OECD Business Sector Database (see Keese et al, (1991)). The attraction of this database is that it contains internationally comparable data. Another attraction is the sectoral coverage: the business sector is defined by the OECD as "the sector whose primary role is the production and sale of goods and services" (Keese et al (1991)). This definition includes public enterprises, but excludes other parts of the public sector. It therefore includes all "for profit" production centres which are likely to be influenced by exchange rate uncertainty in the way discussed in Section II, while omitting the "not for profit" production centres also included in GDP where exchange rate uncertainty may have a very different impact. Nevertheless our business sector definition is considerably broader than just manufacturing.

In constructing a measure for Tobin's Q we follow Sensenbrenner (1991). We approximate Q using a stock market price index divided by an estimate of the value of the capital stock. The use of a stock market index in place of a direct measure of stock market capitalisation is a simplification made necessary because it is difficult to obtain internationally comparable capitalisation data. We can cite the results of various robustness checks reported by Sensenbrenner to justify our decision. The estimated value of the capital stock is represented by the value of the business sector capital stock as constructed by the OECD and discussed in Keese et al (1991).

Our financial data, including exchange rates and stock market prices, were taken from the IMF's International Financial Statistics. Plots of investment, output are provided in Figure 1 and of our measures of Tobin's Q in Figure 2.

III.3 Exchange Rate Volatility

As early as the middle of the 1980s a number of authors (for example, Kenen and Rodrik (1986)) were using rolling standard deviations of the real exchange rate in their empirical work. Such measures have also been used in a series of papers which examined the influence of exchange rate volatility on bilateral trade: examples include Koray and Lastrapes (1989), Lastrapes and Koray (1990) and Chowdury (1993). For example, Koray and Lastrapes (1989) employed a volatility measure defined as

$$V_t = \left[\frac{1}{m}\sum_{i=1}^{m}\left(Z_{t-i} - Z_{t-i-1}\right)^2\right]^{\frac{1}{2}} \qquad (3.2)$$

where Z is the log of the real exchange rate. Similar measures have also been used in work on investment.[7] The size of the window used to construct these measures, m, was typically eight or twelve periods for quarterly data. A common finding was that the results were not sensitive to the choice of window (see the papers cited above). More recently a number of variants of these rolling standard deviations have been introduced. In particular, work by Goldberg (1993) and Campa and Goldberg (1995) on investment has made use of measures which are scaled by the sample mean of the exchange rate.

In the work reported here we adopt (3.2) as our measure of exchange rate volatility, but make one important innovation. Whereas earlier studies assumed a zero (or constant) mean in calculating the rolling standard deviation, we do not. Such an assumption carries the implication that there is no expected change in the "trend" or "equilibrium" exchange rate. That assumption is clearly inconsistent with the possibility that the long run exchange rate evolves over time in some systematic, low frequency way. The point is even more persuasive when we consider the consistency of our volatility measure with the notion of a systematic movement in the exchange rate that is used in our decomposition of exchange rate uncertainty. Our volatility measure is therefore calculated as a moving standard deviation around the same time varying long run equilibrium exchange rate that is used in our calculation of the systematic movements in the exchange rate.[8]

III.4 Systematic Exchange Rate Movement

We also need to decide upon an empirical measure of the systematic movement in the exchange rate. In effect this means selecting a suitable measure of the long run equilibrium or secular trend in the exchange rate. Once this is done, we define a systematic movement as the deviation of the actual exchange rate from this equilibrium path, and then take a moving standard deviation of these deviations as our measure of volatility. That defines "a" as a long run misalignment, and "s" as a measure of short term random variability. The natural interpretation is that if the exchange rate is away from its long run equilibrium value there is an expectation that there will be a systematic movement back towards that equilibrium.[9]

The choice of a measure of the equilibrium exchange rate

There are two principal alternatives to calculating equilibrium exchange rates. The first is based upon Purchasing Power Parity (PPP); the second collects together a set of measures that can loosely be labelled as "structural" or "behavioural" approaches. Examples of the latter approach include the NATREX model of Stein et al (1997) and the FEER popularised by Williamson (1985) and recently applied in an extensive study by Wren-Lewis and Driver (1998).

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[7] See the survey paper by Carruth et al (1998).

[8] An alternative approach would have been to construct a GARCH based measure of exchange rate volatility. Such models have not made a large impact upon either the trade or investment areas. In fact we are aware of only a few papers in the trade literature, including Holly (1995), and none in the investment literature. The probable reason is GARCH models work less well with low frequency data. We are using quarterly data, the highest frequency at which aggregate investment data is available, which means it is unlikely that we would be able to obtain reasonable estimates of exchange rate volatility with GARCH models. That was borne out in preliminary experiments when we tried it.

[9] Pugh et al (1998) place a similar interpretation on a term they refer to as an "exchange rate swing", derived from Krugman (1989), which they include in their empirical work on trade.

The main advantage of PPP is its intuitive simplicity. There is a certain attraction of the idea that, in the absence of impediments to trade, the nominal exchange rate between two countries will eventually equalise the purchasing power of the units of currency in the domestic and foreign economies. Further, there seems to be an empirical consensus that "weak form" PPP (in which there is evidence of cointegration, but not homogeneity) holds for the period of floating exchange rates since the breakdown of Bretton Woods. However, the speed of adjustment towards the implied equilibrium is very slow (see MacDonald (1999)) and this throws some doubt upon the validity of PPP as an *operational* equilibrium concept, at least for a study of the current type. At the same time, the alternative "structural" approaches such as the NATREX and the FEER suffer from their need to base estimates upon a fully specified structural model. This means that estimates are potentially sensitive to the specific choice of model (for an illustration see Bayoumi et al (1994)). [10]

We experimented with several methods of "trend" extraction, including those available in the STAMP package written by Koopman et al (1995), and a selection of a selection of more "mechanical" approaches including linear trend extraction and the extraction of a two-knot cubic spline. We finally settled on the Hodrick Prescott (HP) filter to extract the "trend" real effective exchange rate.

In order to minimise the sensitivity of the detrending method to the starting and ending values in the sample we used a substantially longer sample period for the detrending than we use for estimating our investment equations [11]. The HP filter generated plausible estimates of the equilibrium real effective

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[10] For our purposes both PPP and the "structural" approaches suffer from an additional problem in that they are both usually estimated using purely bilateral exchange rate data. In our model, a firm considering its investment decision will be concerned about revenues expressed in domestic currency which arise from exchange rate movements in *all* relevant foreign markets, not just those of a single country. It is therefore necessary for us to take account of exchange rate misalignment with *all* the trading partners of a given country. In principle we could do this by including measures based on all the relevant bilateral exchange rates. However, this will rapidly reduce the degrees of freedom in our investment equations. Consequently it makes more sense to make use of some measure constructed from effective exchange rate data.

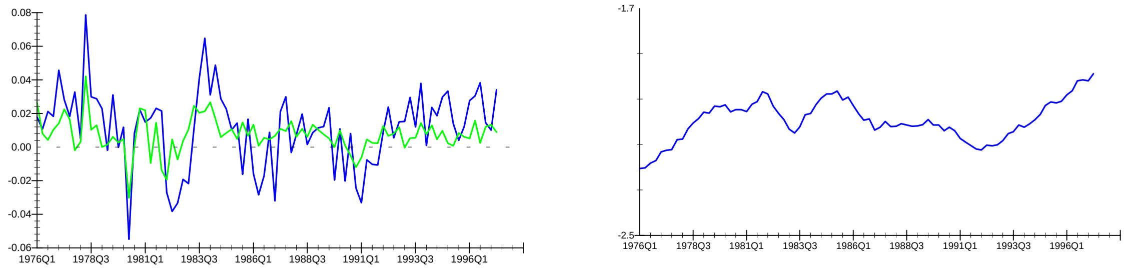
[11] See, for example, Wallis (1996) for a discussion of these problems. In addition to the sensitivity of detrending to sample start and end points, it is also notable that the value of smoothing parameter λ in the HP filter was set at the commonly used value of 1400. But this value was originally selected to remove cycles of the frequency of the US business cycle in output. There is little reason to suggest that this parameter choice should be appropriate either across different countries; or for trend, cycle extraction in other data series. In practice we have to judge the measures by their basic plausibility and their empirical performance.

exchange rates in the sense that they looked to be sensible attractors for the raw series. The HP measures also perform well in the investment equations we estimate.

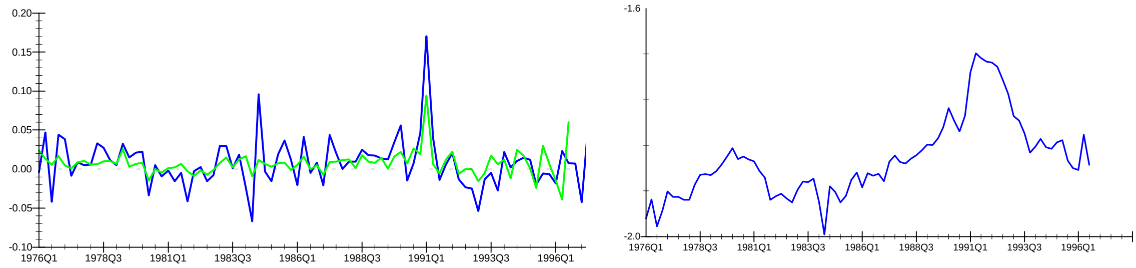
Figure 3 shows the HP trend for the log of the real effective exchange rate, alongside the raw series, for each of the countries considered in this study. The associated measure of systematic movement is given in the plots on the right hand side of the figure. Figure 4 shows the volatility measure described in III.3.

Figure 1: Δln(investment), Δln(output) and ln(investment/output)

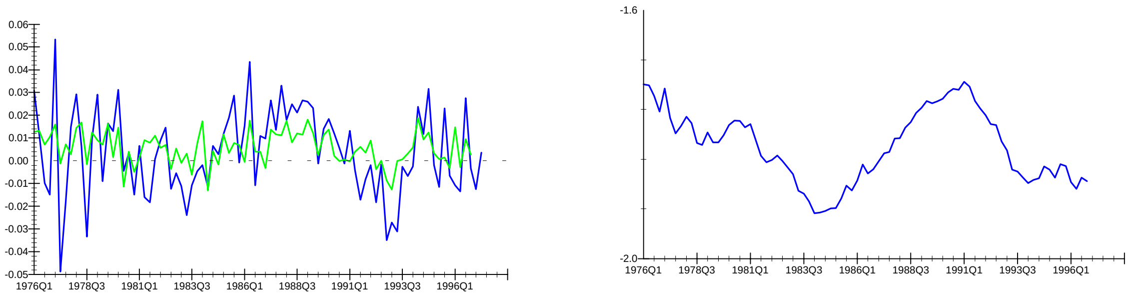
UNITED STATES



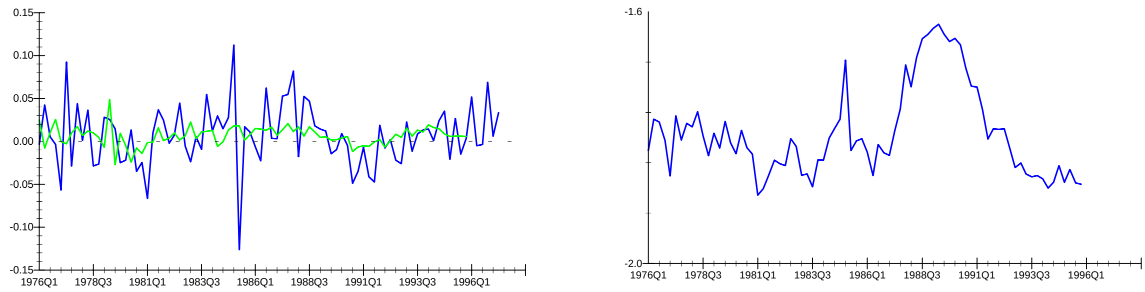
GERMANY



FRANCE



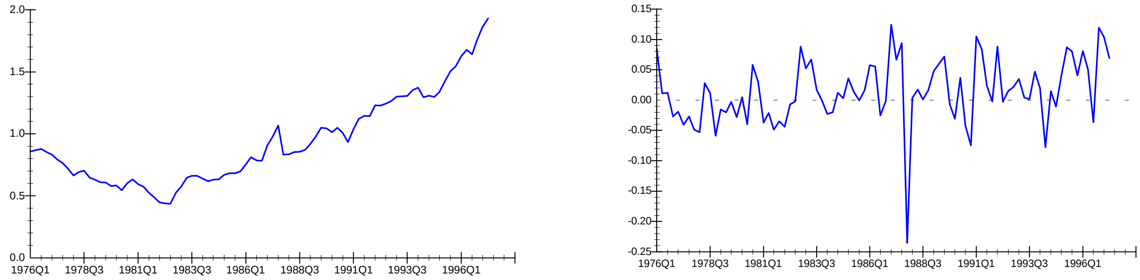
UNITED KINGDOM



Note: The more volatile series in the chart on the left is Δln(investment) in every case, while the right hand panel shows ln(investment/output)

Figure 2: Tobin's Q - level and first difference

UNITED STATES



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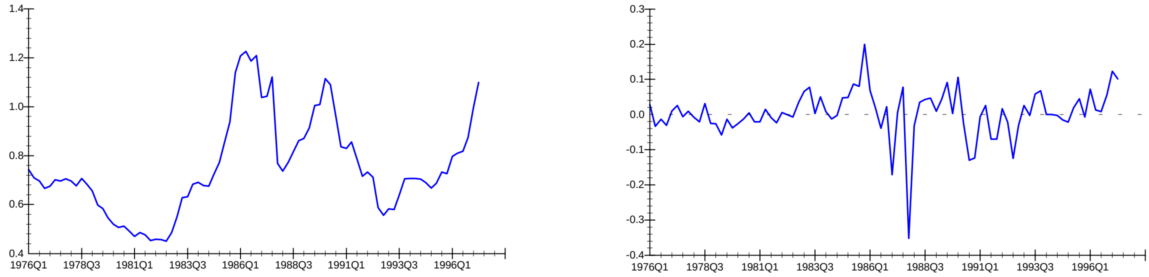

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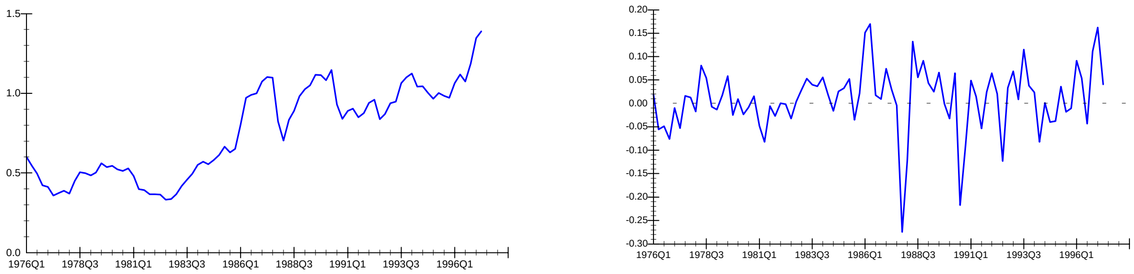

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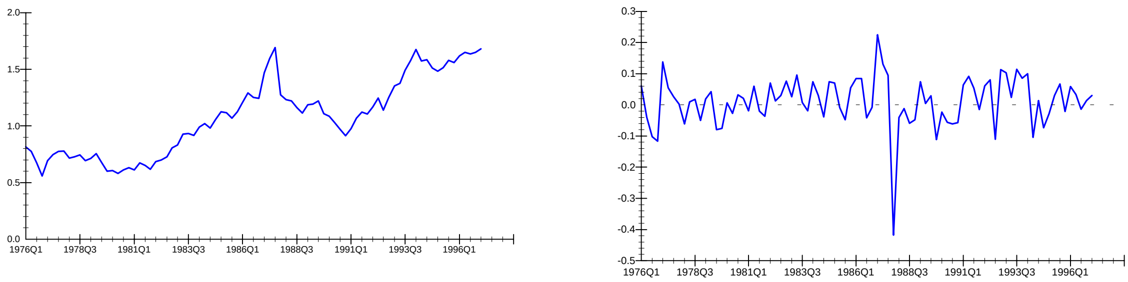
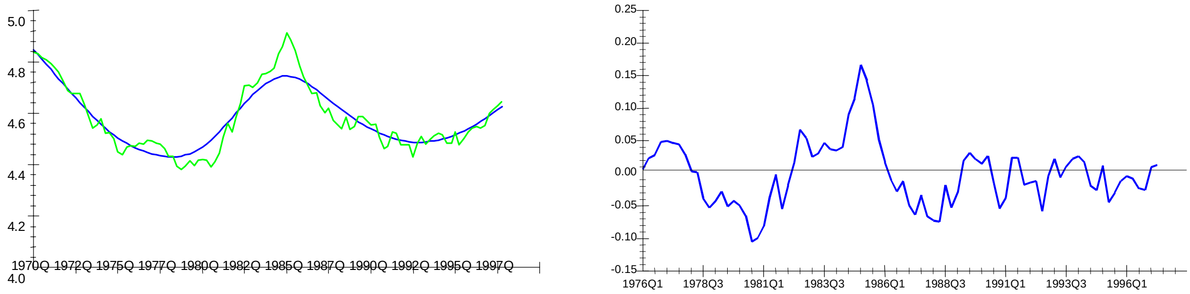


<u>Figure 3: Actual & “Equilibrium” Real Effective Exchange Rates, and their Misalignments as Deviations from the Equilibrium Measure.</u>

UNITED STATES



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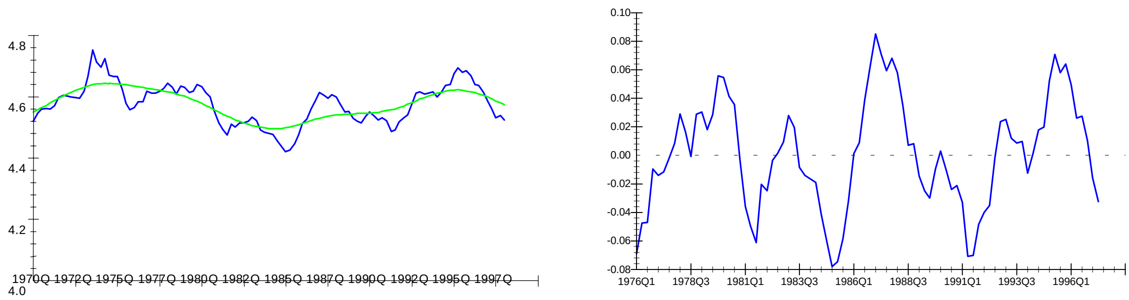

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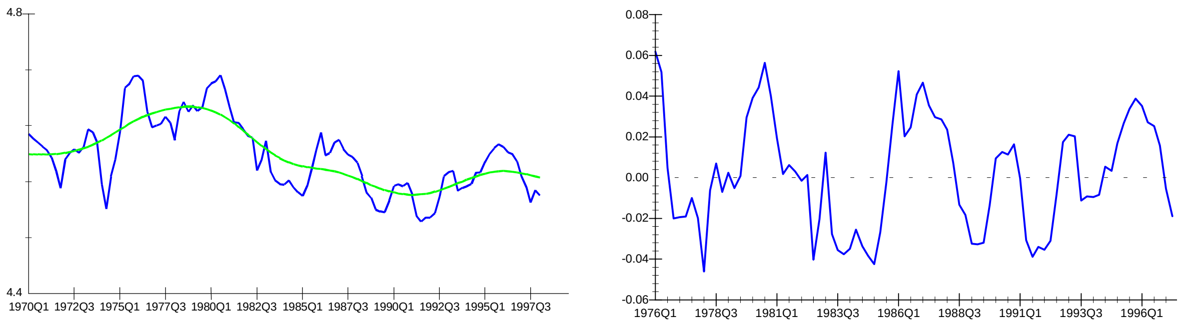

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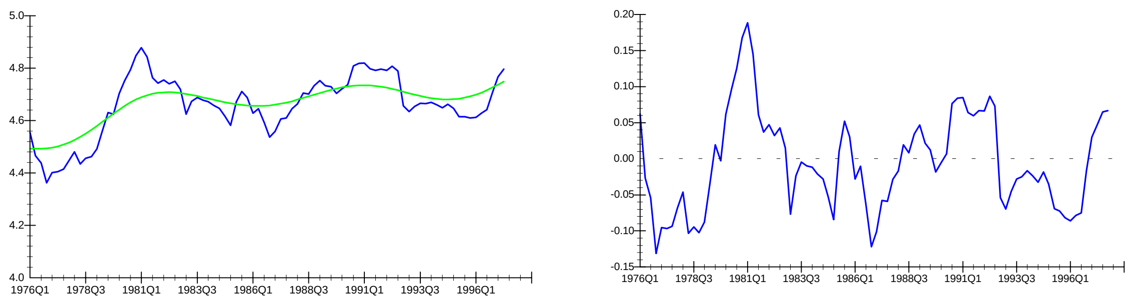
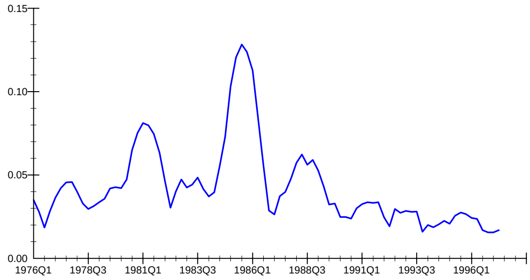


Figure 4: Exchange Rate Volatility. *(scaled by the mean misalignment)*

UNITED STATES



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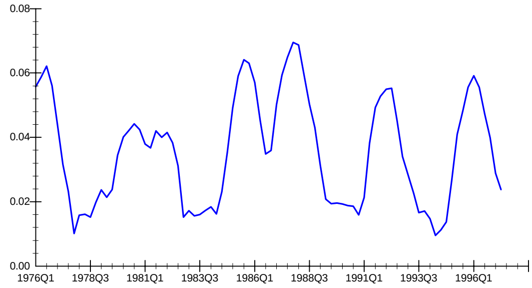

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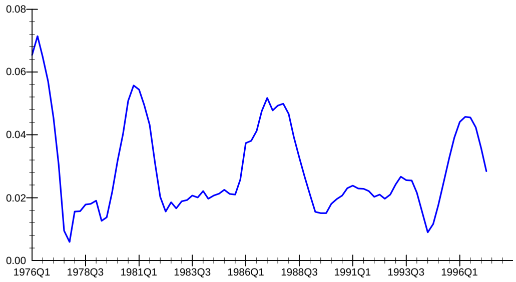
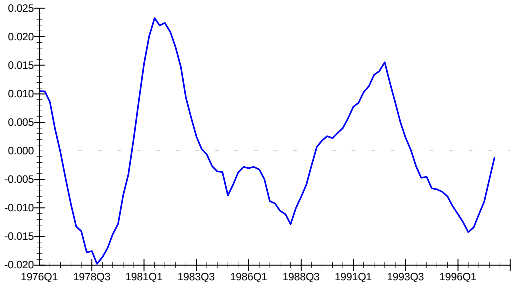


UNITED KINGDOM



IV. RESULTS

In this Section we present estimates of our investment equations for four OECD economies, the United States and three European countries (France, Germany and the United Kingdom). The estimation period runs from 1976 Q1 to 1997 Q2. Estimates for Germany are curtailed in 1990 Q4 to avoid any problems with post unification data. All estimation is by OLS and was carried out in Microfit 4.0 (see Pesaran and Pesaran (1997) for details).

Our starting point is an investment equation which incorporates short and long run dynamic terms in Tobin's Q and output, augmented with misalignment and volatility terms as discussed in Section III. In each case, we started our specification search with long-run output-investment homogeneity imposed and arrived at the final specifications using the usual general to specific techniques. A consequence of this approach is that a particular reported equation may not include either volatility or misalignment terms if they become insignificant at some point during the specification search. We also find that, in some cases, the misalignment or volatility terms can have a transient, but no long run, influence upon investment.

Our estimates for the basic equations are reported in as Equation (1) in Tables 1(a) to 1(d). These equations pass a range of standard diagnostic tests that are also reported in Table1.

In Table 2 we provide a summary of the long run effects of Tobin's Q, volatility and misalignment upon investment. As these variables enter the equations as levels rather than logs, a standard long run solution will yield a semi-elasticity (in this case the proportional effect upon investment of a unit increase in the absolute value of the regressor). To allow unit free comparisons of the long run solutions, Table 2 also provides an estimate of the full elasticity (ε) calculated as the semi-elasticity multipled by the sample mean of the regressor. Using a sample moment to rescale the semi-elasticity in this way, can create problems of interpretation when that moment is less than zero. In these cases we have relied upon the semi-elasticity in judging the direction of a long run effect.

On comparing the four basic equations in Table 1 it becomes clear that there is little consistency in the results over our four economies. Looking at Equation (1) for the UK there was is no evidence of significant effects from either volatility or misalignment and so these terms do not appear in the equation. The German equation does pick up significant negative volatility effects in the long run, although we can only find evidence of a temporary positive effect from misalignment. France and the US do demonstrate some similarities in that volatility has positive effects upon investment and misalignment negative effects in both countries.[12]

[12] This statement is based upon a comparison of the signs of the semi elasticities in Table (2). The sample mean for the US misalignment measure is a small negative number which, although useful for scaling purposes, causes the sign of the elasticity to be the opposite of the semi-elasticity.

In Section II of the paper we noted that our theoretical model implied that it was likely that exchange rate misalignments and volatility could influence investment in a non-linear way. Equation (1) does not allow for such effects, and we now go onto consider a number of modifications of basic equations which test for the presence of non-linear effects.

Our starting point was to examine the possibility that volatility and misalignments interact with other. To do this we estimated two additional sets of equations. In the first we included a multiplicative interaction term between volatility and misalignment and in the second we included a term in the misalignment divided by volatility. Neither of these specifications performed particularly well in any of our four economies – the interaction terms were either insignificant or if they were significant they were outperformed by other specifications which we discuss below. As a result of this poor performance, their results are not reported in Tables 1 and 2.

We then focused on the possibility of non-linearities taking the form of an asymmetric response to a misalignment in the exchange rate. Here we separated out movements in the exchange rate above equilibrium from those below by including an additional regressor in positive misalignments (referred to as "excr malign asymtric" in the listings of Equation (2)). The overall significance of the asymmetry can then be tested using a straightforward t-test on the asymmetric term. The results here were more encouraging.

Our final specification also focused upon the possibility of a non-linear response to exchange rate misalignment, but this time imposed symmetry around the equilibrium exchange rate. We considered the possibility of differential effects of "small" versus "large" misalignments. Various functional forms are possible here, including reciprocals. A reasonably flexible approach introduces the square of the misalignment. So that the positive and negative signs would be preserved, we multiplied the square by minus one when the exchange rate was beneath its equilibrium value, this gives the term "sign preserv malign sqr". The results achieved with this specification appear in the tables as Equation (3).

Table 1(a): US Investment Equations

	Eq. (1)		Eq. (2)		Eq. (3)	
intercept	-0.2003 (.060)		-0.1194 (.048)		-0.1320 (.050)	
Δln(GDP)	1.2823 (.189)		1.3088 (.177)		1.2787 (.185)	
Δln(investment(-3))	0.1974 (.081)		0.2571 (.078)		0.2582 (.083)	
ln(invest(-4)/GDP(-1))	-0.0862 (.026)		-0.0580 (.023)		-0.0621 (.024)	
excr volatility (-1)	0.7288 (.284)		0.8135 (.207)		0.5257 (.200)	
excr volatility (-2)	-1.0795 (.459)		-0.8135 (*)		-0.5257 (*)	
excr volatility (-3)	0.4553 (.275)					
excr misalignment (-1)			0.1320 (.058)			
excr misalignment (-2)	-0.7406 (.040)					
Δ Tobin's Q (-2)	0.0129 (.007)		0.0631 (.033)		0.0644 (.034)	
Δexcr malign asymtric (-2)			-0.6684 (.161)			
excr malign asymtric (-3)			-0.3144 (.092)			
sign preserv malign sqr (-2)					-1.2716 (.467)	
R-Bar-Squared	0.5078		0.5749		0.5229	
F statistic (all slopes)	F(8,77)	11.961[.000]	F(8,77)	15.371[.000]	F(6,79)	6.528[.000]
Normality	$\chi^2(2)$	3.710[.156]	$\chi^2(2)$	2.396[.302]	$\chi^2(2)$	5.034[.081]
Functional Form	F(1,76)	0.106[.745]	F(1,76)	0.813[.370]	F(1,78)	0.087[.769]
Serial Correlation	F(1,76)	0.213[.646]	F(1,76)	0.196[.659]	F(1,78)	0.014[.905]
	F(4,73)	0.189[.944]	F(4,73)	1.726[.153]	F(4,75)	1.221[.309]
	F(8,69)	0.367[.934]	F(8,69)	7.432[.115]	F(8,71)	0.783[.619]
Heteroscedasticity	F(1,84)	0.0003[.986]	F(1,84)	0.055[.815]	F(1,84)	0.004[.948]
ARCH	F(1,76)	0.699[.406]	F(1,76)	1.546[.218]	F(1,78)	1.914[.170]
	F(4,73)	1.753[.148]	F(4,73)	2.939[.026]	F(4,75)	1.300[.278]

Sample 1976Q1 to 1997Q2
Dependent variable is Δln(investment)]
* Term enters as a difference term i.e. $\Delta x_{(-k+1)}$, the relevant standard error is given with $x_{(k+1)}$

Table 1(b): UK Investment Equations

	Eq. (1)		Eq. (2)	
intercept	-0.2469 (.071)		-0.2552 (.072)	
Dummy variable DD851	0.1207 (.019)		0.1223 (.018)	
Tobin's Q (-1)	0.0965 (.037)		0.0926 (.036)	
Tobin's Q (-2)	-0.0839 (.037)		-0.0740 (.037)	
Δln(investment(-4))	0.2494 (.084)		0.2920 (.087)	
excr misalignment (-3)			-0.2665 (.096)	
Δln(invest(-4)/GDP(-1))	-0.1314 (.040)		-0.1091 (.040)	
excr malign asymtric (-3)			0.4450 (.162)	
R-Bar-Squared	0.4359		0.4786	
F statistic (all slopes)	F(5,75)	13.364[.000]	F(7,73)	11.490[.000]
Normality	$\chi^2(2)$	0.9340[.630]	$\chi^2(2)$	0.2058[.902]
Functional Form	F(1,72)	2.2920[.130]	F(1,72)	1.2110[.275]
Serial Correlation	F(1,74)	0.6126[.436]	F(1,72)	2.4690[.120]
	F(4,71)	0.4734[.755]	F(4,69)	0.9219[.456]
	F(8,67)	0.7860[.617]	F(8,65)	1.0616[.401]
Heteroscedasticity	F(1,79)	0.0160[.900]	F(1,79)	0.0640[.801]
ARCH	F(1,74)	0.2032[.653]	F(1,72)	0.1821[.144]
	F(4,71)	0.7564[.557]	F(4,69)	1.0822[.372]

Sample 1976Q1 to 1996Q1
Dependent variable is Δln(investment)

Table 1(c): French Investment Equations

	Eq. (1)	Eq. (2)	Eq. (3)
intercept	-0.1498 (.044)	-0.1469 (.041)	-0.1582 (.042)
Dummy variable DD771	0.0394 (.009)	0.0414 (.008)	0.4118 (.009)
Δln(GDP)	1.3258 (.198)	1.3249 (.184)	1.2729 (.190)
Δln(invest(-1))	0.1726 (.075)	0.1560 (.069)	0.1580 (.072)
Δln(invest(-3))	0.2045 (.071)	0.1723 (.067)	0.1807 (.068)
Δln(invest(-4))	0.1815 (.069)	0.1840 (.064)	0.2120 (.067)
excr volatility (-1)	0.7272 (.330)		
excr volatility (-2)	-1.5110 (.570)	-1.0268 (.253)	-0.8677 (.250)
excr volatility (-3)	1.0137 (.328)	1.0268 (*)	0.8677 (*)
excr misalignment (-4)	-0.1446 (.078)	-0.1359 (.048)	-0.1147 (.048)
ln(invest(-1)/GDP(-1))	-0.0757 (.024)	-0.0754 (.022)	-0.0827 (.023)
excr malign asymtric (-1)		0.3532 (.087)	
sign preserv malign sqr (-2)			5.6544 (1.68)
R-Bar-Squared	0.6193	0.6704	0.6502
F statistic (all slopes)	F(10,73) 4.503[.000]	F(9,74) 19.761[.000]	F(9,74) 18.141[.000]
Normality	$\chi^2(2)$ 1.963[.375]	$\chi^2(2)$ 1.444[.486]	$\chi^2(2)$ 1.201[.549]
Functional Form	F(1,72) 0.024[.877]	F(1,73) 0.043[.837]	F(1,73) 0.012[.911]
Serial Correlation	F(1,72) 0.179[.674]	F(1,73) 0.240[.625]	F(1,73) 0.170[.681]
	F(4,69) 0.337[.852]	F(4,70) 0.585[.674)	F(4,70) 0.805[.526]
	F(8,65) 0.618[.760]	F(8,66) 0.774[.627]	F(8,66) 0.956[.478]
Heteroscedasticity	F(1,82) 3.319[.072]	F(1,82) 4.130[.045]	F(1,82) 4.334[.040]
ARCH	F(1,72) 1.743[.191]	F(1,73) 0.569[.453]	F(1,73) 1.556[.216]
	F(4,69) 0.929[.452]	F(4,70) 1.075[.376]	F(4.70) 1.128[.351]

Sample 1976Q1 to 1996Q4

Dependent variable is Δln(investment)]

* Term enters as a difference term i.e. $x_{(-k+1)}$, the relevant standard error is given with $x_{(k+1)}$

Table 1(d): German Investment Equation

	Eq. (1)
Intercept	-0.4624 (.125)
Dummy variable D763	-0.0499 (.011)
Dummy variable D763(-1)	-0.0310 (.011)
Dummy variable DD842	-0.0604 (.010)
Δln(GDP)	1.3859 (.246)
Tobin's Q (-10)	0.0587 (.015)
Δexcr misalignment (-1)	0.2226 (.104)
excr volatility (-3)	-0.3638 (.135)
ln(invest(-1)/GDP(-1))	-0.2296 (.063)
R-Bar-Squared	0.7292
F statistic (all slopes)	F(8,49) 20.182[.000]
Normality	$\chi^2(2)$ 3.796[.150]
Functional Form	F(1,48) 0.025[.876]
Serial Correlation	F(1,48) 0.002[.969]
	F(4,45) 1.382[.255]
	F(8,41) 1.291[.275]
Heteroscedasticity	F(1,56) 1.044[.311]
ARCH	F(1,48) 0.067[.067]
	F(4,45) 0.293[.881]

Sample 1976Q1 to 1990Q4

Dependent variable is ΔIn(investment)]

Notes to Table 1

Estimation by OLS. Standard errors are in parentheses, and probability values for test statistics are in square brackets.

Table 2: Long Run Elasticities

US	Eq. (1)		Eq. (2)		Eq. (3)	
	ε	semi ε	ε	semi ε	ε	semi ε
ln(GDP)	1.0		1.0		1.0	
excr volatility	0.0519	1.2135				
excr misalignment	0.0053	-8.5916				
excr misalignment > 0			0.0019	-3.1448		
excr misalignment < 0			-0.0014	2.2759		
sign preserv malign sqr					-0.0299	-21.9241

UK	Eq. (1)		Eq. (2)	
	ε	semi ε	ε	semi ε
ln(GDP)	1.0		1.0	
Tobin's Q	0.1005	0.0959	0.1286	0.1705
excr volatility				
excr misalignment				
excr misalignment > 0			-0.0104	1.6361
excr misalignment < 0			0.0733	-2.4427
sign preserv malign sqr				

France	Eq. (1)		Eq. (2)		Eq. (3)	
	ε	semi ε	ε	semi ε	ε	semi ε
ln(GDP)	1.0		1.0		1.0	
excr volatility	0.8844	3.0370				
excr misalignment	-0.0039	-1.9102			-0.0028	-1.3869
excr misalignment > 0			0.0059	2.8817		
excr misalignment < 0			-0.0037	-1.8024		
sign preserv malign sqr					0.1398	68.372

Germany	Eq. (1)	
	ε	semi ε
ln(GDP)	1.0	
Tobin's Q	0.1928	0.2557
excr volatility	-0.0571	-1.5845
excr misalignment		
excr misalignment > 0		
excr misalignment < 0		
sign preserv malign sqr		

Note – The semi-elasticity gives the proportional long run change in investment following an a unit absolute increase in the independent variable.

IV.1 Overall Results

The most successful specification across all the countries is Equation (2).

The third specification, involving sign preserving misalignments, was unsuccessful for Germany and the UK. However, we did have some success in the case of our French and the US. The sign preserving non-linear term leads to a positive effect from misalignments in France and a negative effect in the US – but in both cases there are larger effects from large misalignments than from small ones. In terms of volatility both equations show a negative effect upon investment, although in the case of France this is only an impact effect and there is no long run role for volatility at all.

Looking at Equation (2), for both France and the UK there is a positive effect from misalignments when they are above the equilibrium value of the exchange rate and negative effects when they are below. For Germany there were no significant asymmetric misalignment terms and our preferred equation remains the basic Equation (1). However, there is some consistency in the effects of exchange rate volatility. We do not find evidence of long run volatility effects for France, UK or US, though in both the French and US equations there is a negative impact from volatility in the short run. This is consistent with the negative short run impact in our preferred equation for Germany, Equation (1).

We now turn to a more detailed look at the results for each individual country.

IV.2 United States

The basic US specification is supported by the standard diagnostic tests listed in table 1(a). there is no evidence of significant non-normality, serial correlation, heteroscedasticity or incorrect functional form. The exchange rates terms are jointly and individually significant. The basic US equation incorporates long run effects from output, misalignments and exchange volatility. Tobin's Q only influences the short run dynamics. The freely estimated output elasticity is insignificantly different from unity. In the US case the t_{ECM} value is relatively large and therefore supports the error correction formulation. With a relatively short span of data, it is likely that the t_{ECM} in the freely estimated error correction model may provide a more reliable indication of the existence of cointegration than many of the available direct tests (see Kremers, Ericsson and Dolado (1992)). Cusum and Cusum Squared tests, along with Chow predictive failure and parameter stability tests, do not identify any problems.

The basic specification is dominated by those incorporating some nonlinearities. Equation (3) provides evidence that big overvaluations (ie. positive missalignments) depress investment more than small overvaluations, undervaluations have the opposite effect. Again this equation is supported by the diagnostic tests. But the best equation in terms of fit is provided by Equation (2), the asymmetric specification. The estimated coefficients suggest that, when the exchange rate is above long run equilibrium, there is significant additional downward pressure on investment. Since volatility (s^2) is quite large (figure 4), and if anything increases rather than decreases investment whether small or large - see table 2, this combination of parameters suggests Case C of the theoretical model (section II.4) applies in the US.

IV.3 United Kingdom

Superficially the UK equation performs well. The unit coefficient on output is easily data admissible and whilst the equation residuals initially failed a normality test, but this reflects a "blip" in investment caused by a pre-announced change in the tax treatment of investment which was captured through the introduction of a single (0, 1, -1, 0) dummy 1985. With this adjustment, Cusum and Cusum Squared tests are accepted, and there is no evidence of serial correlation, heteroscedasticity, ARCH effects or functional form misspecification. The Chow parameter stability tests are also satisfactory.

We were able to identify a significant but small positive effect of Tobin's Q on investment. The plot of this data in Figure 4 along with leverage measures of the regression, illustrate that the 1987 stock market crash is rather dominant.

We were able to estimate an asymmetric effect from exchange rate misalignments (Equation (2)) but no volatility effects could be identified. A real effective exchange rate above equilibrium is expected to boost investment, whilst the opposite misalignment is estimated to result in a proportionately larger drop. Since volatility (large or small) has no perceptible effect on investment, while volatility itself is quite small, this suggests we are dealing with a case C (or possibly Case A) from the theoretical model.

However, the UK equation may be the least robust of the set for a different reason. Reviewing the charts presented earlier, the equilibrium exchange rate plot for the UK shows quite persistent deviations in the real effective exchange rate from its equilibrium value despite a reasonably strong error correction term in the investment equation. Hence it seems likely that changes in the behaviour of the equilibrium exchange rate may have occurred during the estimation period. The period encompasses such diverse policies as "free" floating, shadowing the DM, ERM entry and subsequent exit and finally the pursuit of an independent inflation target accompanied by a return to a freely floating exchange rate. It is doubtful whether a slowly evolving view of the equilibrium real effective exchange rate is appropriate in this case.

IV.4 France

The French specifications display slower adjustment, but are again quite well determined. The t_{ECM} value at -0.07 is small but significant. Once again a single (0, 1, -1, 0) dummy variable was required due to outliers in 1977. A glance at Figure 3 reveals that investment was unusually volatile at this time. With the dummy included there is no evidence of significant non-normality, nor do the other standard diagnostics in Table 1 reveal any problems. On the basis of the stability tests too, the final specification performs well.

The freely estimated output elasticities were only marginally lower than unity and certainly not significantly so. We were unable to identify any significant effects from Tobin's Q, or a real cost of capital measure. But we did identify a number of exchange rate effects, which were both individually and jointly statistically significant. Exchange rate volatility exerts a small positive impact on investment in the long run, although the dynamics are themselves far from smooth. In the alternative specifications, exchange rate volatility only has a temporary negative impact. The most basic specification suggests that misalignments reduce investment, though once again this is dominated by the alternative specifications. Large overvaluations (undervaluations) tend to have an increasingly positive (negative) effect on investment (equation 3) though the best fit is achieved with the asymmetric specification (equation 2). When the exchange rate is above its long-run equilibrium value, investment is boosted and by an asymmetrically large amount. That suggests case B of the theoretical model

IV.5 Germany

The German equation too is generally supported by well-behaved diagnostic tests. Two (0, 1, -1, 0) dummy variables were introduced, with steps up in 1976.3 and 1984:2. This was required to capture outliers in the equation residuals which appear to be associated with abnormal output fluctuations (see figure 3). The introduction of these extra variables enabled the equation residuals to satisfy the normality test. There is no evidence of serial correlation, heteroscelasticity or incorrect functional forms. Imposing the coefficients on the dummy variables at their full sample value enabled us to undertake some stability tests. Chow tests, along with Cusum and Cusum Squared plots do not identify any problems. Note that the German sample period is curtailed at 1990 Q4 due to the data problems and different transitional caused by reunification.

The basic specification displays a strong error correction coefficient that implies that investment adjust to eliminate 23% of the previous quarters' disequilibrium. The t_{ECM} value is significant. The dynamic adjustment in general is relatively fast, although Tobin's Q has a slow acting impact which is not detectable for the first two years.

As noted earlier, no evidence of significant asymmetric misalignment effects, nonlinearities or interaction effects could be found. Misalignment only appears to affect investment in the short-run. The short-run misalignment and long run volatility terms themselves imply that an undervalued exchange rate and greater volatility would both tend to reduce investment. These results suggest Germany fits into Case A (rather than B or C) of the theoretical model. The implied long run elasticities presented in Table 2 show that impact of volatility is far larger than that for the United States. Sensitivity analysis suggests that these estimates are reasonably robust. Finally, it is worth mentioning that despite being slow to take effect, the long run elasticity of investment with respect to Tobin's Q calculated at the sample mean is actually a little larger than that in the US or UK.

V. POLICY IMPLICATIONS

One way to use the results presented above is to ask how attractive a reduction in exchange rate uncertainty would be for boosting investment? This is a general question, but must have been particularly important as a principal motivation for the move to EMU in January 1999. In this sense it is surprising that there are few papers which have attempted such an exercise.

The answers are clear cut but not emphatic as regards size. Exchange rate volatility appears to reduce investment on average; but the way in which it does so depends on the industrial structure of the economy concerned; on the extent of any associated misalignment; and on whether the currency is over or undervalued. Principally an overvalued currency may damage investment, but not always (e.g. not in the US or UK) depending on the industrial structure. As a result, the impact of exchange rate misalignments and volatility must vary across countries.

Finally one may ask if our results imply any predictions about investment in Europe after the introduction of the Euro. The answer is perhaps rather little, both because the effects of locking exchange rates may be rather different in different places - because industrial structures differ and that would produce different investment responses - and because of the potential Lucas critique that investment behaviour may change from that in our estimated equation. However, more important than that, it is not obvious to what extent locking nominal exchange rates within Europe will actually reduce either nominal effective volatility or indeed real volatility. For example, EMU and the introduction of the euro do not eliminate exchange rate volatility between the euro and non-euro currencies. That means we should really define separate measures of misalignment and volatility to capture both within EU-11 characteristics and those outside. As the change in the nature of the within EU-11 real exchange rate movements is likely to result in changes in underlying behaviour in response to changed incentives, a plausible study will need to await further data to estimate these effects.

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APPENDIX: CONDITIONS FOR THE FREQUENCY AT WHICH THE INVESTMENT TRIGGER PRICE IS EXCEEDED NOT TO INCREASE WITH MISALIGNMENTS IN THE EXCHANGE RATE

Equation (2.2) shows that, at time t, P follows a log normal distribution with mean

$$\left(\alpha - \sigma^2/2\right)t$$

and variance $\sigma^2 t$ (Dixit and Pindyck, 1994). We can therefore write the probability of getting a price above the trigger price as

$$G(P_H) = \int_{P_H}^{\infty} \frac{1}{P\sqrt{2\pi\sigma}} e^{-\frac{1}{2}\left(\frac{\log p - \mu}{\sigma}\right)^2} dp \qquad \text{(A1.1)}$$

where, for this paper, σ^2 is fixed. But α varies, where $\mu = \alpha - \sigma^2/2$, so that $d\mu = d\alpha$.

We need to show $\partial G(P_H)/\partial\alpha \leq 0$ for the necessary and sufficient conditions (2.14) to (2.16) to be a valid description of when investment expenditures will fall with exchange rate misalignments. Without loss or generality consider time period t=1. Similarly let the degree of misalignment change (increase) by $d\alpha = \alpha_1 - \alpha_0$ where $\alpha_1 > \alpha_0$, and where

$$\mu_1 = \alpha_1 - \sigma^2/2 > \mu_0 = \alpha_0 - \sigma^2/2 > 0$$

and σ^2 remains constant. To get $\partial G(P_H)/\partial\alpha \leq 0$, we need to show

$$G(\alpha_0) = \int_{P_{H0}}^{\infty} \frac{1}{P\sqrt{2\pi\sigma^e}} e^{-\frac{1}{2}\left(\frac{\log p - \mu 0}{\sigma}\right)^2} dp \geq G(\alpha_1) = \int_{PH_1}^{\infty} \frac{1}{P\sqrt{2\pi\sigma}} e^{-\frac{1}{2}\left(\frac{\log p - \mu 1}{\sigma}\right)^2} dp \qquad \text{(A1.2)}$$

Now let $x = \dfrac{\log p - \mu_0}{\sigma}$ and $y = \dfrac{\log - \mu_1}{\sigma}$ so that $dx = dy = 1/(p\sigma)$. Then we need

$$G(\alpha_0)\frac{1}{\sqrt{2\pi}}\int_{x_H}^{\infty} e^{-\frac{1}{2}x^2} dx \geq G(\alpha_1) = \frac{1}{\sqrt{2\pi}}\int_{y_H}^{\infty} e^{-\frac{1}{2}y^2} dy \qquad \text{(A1.3)}$$

where

$$x_H = \frac{\log P_{H0} - \mu_0}{\sigma} \text{ and } y_H = \frac{\log P_{H1} - \mu_1}{\sigma}$$

But this inequality will hold if and only if $x_H \leq y_H$; i.e. if and only if

$$\mu_1 - \mu_0 = \alpha_1 - \alpha_0 \leq \log\left(P_{H1}/P_{H0}\right) = d\log(P_{H0}) \qquad \text{(A1.4)}$$

since $\sigma \neq 0$, as claimed at equation (2.18).