Foreign Direct Investment in Industrial R&D and Exchange Rate Uncertainty in the UK

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Abstract

The purpose of this paper is to investigate the role of exchange rate uncertainty in determining foreign direct R&D investment into the UK. We estimate an econometric model of FDI in R&D, using a panel of manufacturing industries. Our results suggest that an increase in the volatility of the euro-dollar exchange rate tends to relocate R&D investment from the Euro Area into the UK. A rise in the covariance of the Euro and sterling, which would be a certain consequence of the UKs entry into the European Monetary Union, will increase foreign direct R&D investment into the UK.

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1. Introduction

The impact of exchange rate uncertainty on investment has recently received increasing attention from researchers and policymakers. Carruth *et al* (2000) provide a review of the extensive empirical literature and conclude that there is a negative relationship between uncertainty and investment. This is supported by the results in Byrne and Davis (2002) and Bénassy-Quéré *et al* (2001). Although the evidence in Goldberg (1993) and Darby *et al* (1999) is less clear-cut it seems reasonable to conclude that there is general support for the notion that exchange rate volatility affect investment.

In this paper we wish to explore two extensions to this work; First, there is little or no evidence to date of the impact exchange rate uncertainty is likely to have on foreign direct investment in R&D. Secondly we wish to extend the analysis from the current practice of simply considering the volatility of exchange rates to considering also the covariance between exchange rates.

We believe that the introduction of covariance terms is particularly important in the light of the possible entry of the UK into European Monetary Union. In general entry may not mean an overall reduction in exchange rate volatility. If for example we were pegged to the Dollar and then moved to monetary union the overall exchange rate volatility would depend on the relative volatility of the Dollar and the Euro. The one thing however that we are certain of is that if we join monetary union the correlation of the Pound and the Euro will go to one. If therefore we find an effect of covariances in the determination of R&D investment this implies an unambiguous effect of entry into monetary union.

There has been a small amount of work specifically on foreign direct R&D investment. However most of it is survey-based (Cantwell, 1989, Serapio and Dalton, 1999, as well as Florida, 1997, for instance) and little attention has been paid to the volatility question. In the UK, foreign investment in R&D accounts for a significant amount of total R&D, over a third in manufacturing in the late 1990's for example. This part of total R&D may be very sensitive to exchange rate uncertainty effects we argue.

We estimate an econometric model of foreign direct investment in R&D, using a panel of 11 UK manufacturing industries. Our results suggest that an increase in the volatility of the euro dollar exchange rate tends to relocate R&D investment from the Euro Area to the UK. The

UK's entry into EMU must increase the covariance between the sterling dollar and the euro dollar exchange rate. We find that this will tend to relocate foreign direct R&D investment into the UK. Other factors identified to have significant effects on FDI in R&D are the real long-term interest rates, output fluctuations, net capital expenditure and the proportion of business R&D conducted by businesses and funded by the government.

The paper is structured as follows. Section II gives a theoretical framework that demonstrates that risk-averse firms benefit from FDI diversification. Section II.1 and II.2 then generates GARCH estimates of the conditional covariance and the conditional correlation between the dollar sterling and the dollar euro exchange rates. Section III outlines our panel data model of R&D FDI. Section IV describes the empirical results and section V draws some brief conclusion.

2. Benefits of FDI Diversification

Imagine that a firm has a total amount of funds to be invested in R&D (A). This can be split between the home country (1) and a number of foreign countries (2…n) each of which will earn a rate of return, r_i (i=1…n). Assume that there is uncertainty about the rates of return due to nominal exchange rate risk ($\sigma_i^2, \sigma_1^2 = 0$). If a firm chooses to invest w_i as a proportion of its assets in each country (w_i <1, all i, $\sum w_i = 1$) then the total expected return on the firms assets will be

$$E(r) = \sum_{i=1}^{n} w_i E(r_i) \quad [1]$$

and the expected variance of the returns will be given by

$$\sigma^2 = \sum_{1}^{n} w_i^2 \sigma_i^2 + \sum^{n} \sum_{j}^{n} w_i w_j \sigma_{ij} = \sum_{1}^{n} w_i^2 \sigma_i^2 + \sum^{n} \sum_{j}^{n} w_i w_j \rho_{ij} \sigma_i^2 \sigma_j^2 \quad [2]$$

A firm which is purely interested in maximizing expected profits should therefore invest only in the country or countries with the highest return but a firm which is concerned with both maximizing profits and minimizing risk would exploit any correlation between returns which is less than one to reduce the variance of the total return. A correlation coefficient of 1 means that there are no benefits to diversification between the two regions and only the region with the higher return should receive any investment. Of course as the domestic currency is certain, ${\sigma_1}^2 = 0$.

Based purely on these formulae it is not possible to determine the relative weights, as this must involve the full objective function of the firm (that is its desired risk and return characteristics of the firms utility function). However within this framework we can appeal directly to standard portfolio theory (Cuthbertson and Nitzsche, 2001, chapter 10) to state some interesting relationships. If all firms have similar risk return profiles then the return produced by any individual country should be given by the following equivalent of the capital asset pricing model.

$$E(r_i) = r_1 + \beta_i (E(r_m) - r_1) \qquad [3]$$

where

$$E(r_m) = \sum_{i=2}^{n} w_i^* r_i \qquad where \;\; w_i^* = \hat{w}_i / \sum_{j=2}^{n} \hat{w}_j \qquad [4]$$

and $\hat{w}_i$ is the optimal weight of country i in a firms stock of assets, and

$$\beta_i = COV(r_i, r_m) / {\sigma_m}^2 . \qquad [5]$$

This says that if the correlation of a country with the average of countries is very high then the rate of return in that country must be comparable to the rate of return across all countries. But if the country has a low (or even negative) covariance with the other countries then the optimal return in that country may be well below the average and may even be below the rate of return in the home country. This emphasizes the importance of the covariance for the determination of foreign direct investment.

2.1. *Multivariate GARCH Systems*

The standard univariate GARCH model is now very well known but this model suffers from the obvious drawback that it can only be used to produce a measure of the conditional variance of a process. If we are interested in understanding the complete conditional distribution of a group of variables then we need to extend the basic GARCH framework to a multivariate context so that we may consider complete conditional covariance matrices. A number of studies have already used this extension and a number of alternative specifications exist in the literature, Kraft and Engle (1982), Bollerslev, Engle and Wooldridge (1988), Hall, Miles and Taylor (1990), Hall and Miles (1992), as well as Engle and Kroner (1995).

Essentially we are interested in building a model of a complete conditional covariance structure of a set of variables. So consider a set of n variables Y that are generated by the following VAR process:

$$A(L)Y_t = e \; . \qquad [6]$$

This varies from a conventional VAR model as we assume that

$$E(e_t) = 0 \quad and \quad E(e_t e'_t) = \Omega_t \qquad [7]$$

so that the covariance matrix is time varying, we then make the standard ARCH assumption that this covariance matrix follows an autoregressive structure. Estimation of such a model is, in principle, quite straightforward, as the log likelihood is proportional to the following expression.

$$l = \sum_{t=1}^{T} \ln|\Omega_t| + e'_t \Omega_t^{-1} e_t \qquad [8]$$

Standard maximum likelihood (or quasi maximum likelihood) procedures may be applied. The only real difficulty comes in the parameterization of the process generating Ω_t, the natural extension of the standard GARCH formulation very quickly begins to generate huge numbers of parameters.[1]

One of the most popular formulations was first proposed by Baba, Engle, Kraft and Kroner, sometimes referred to as the BEKK (see Engle and Kroner, 1993) representation, this takes the following form:

[1] If we define the VECH operator in the usual way as a stacked vector of the lower triangle of a symmetric matrix then we can represent the standard generalization of the univariate GARCH model as $VECH(\Omega_t) = C + A(L)VECH(e_t e_t') + B(L)VECH(\Omega_{t-1})$, where C is an (N(N+1)/2) vector and A_i and B_i are (N(N+1)/2)x(N(N+1)/2) matrices. This general formulation rapidly produces huge numbers of parameters as N rises (for just 1 lag in A and B and a 5 variable system we generate 465 parameters to be estimated) so for anything beyond the simplest system this system will almost certainly be intractable. A second problem with this system is that without fairly complex restrictions on the system the conditional covariance matrix cannot be guaranteed to be positive semi definite. So much of the literature in this area has focused on trying to find a parameterization which is both flexible enough to be useful and yet is also reasonably tractable.

$$\Omega_t = C'C + \sum_{i=1}^{q} A'_i \, e_{t-i} e'_{t-i} \, A_i + \sum_{j=1}^{p} G'_j \, \Omega_{t-j} G_j \, . \qquad [9]$$

This formulation guarantees positive semi definiteness of the covariance matrix almost surely and reduces the number of parameters considerably. However even this model can give rise to a very large number of parameters and further simplifications are often applied in terms of making A and B symmetric or diagonal.

2.2. *Results of the Multivariate GARCH Model*

The objective of this section is to generate estimates of the conditional covariance and the conditional correlation between the dollar-sterling rate and the dollar-euro rate. We have chosen to consider two alternative possible definitions of the exchange rate, nominal bilateral rates and real bilateral rates based on relative consumption deflators.

We therefore formulate a pair of simple first order autoregessions for the log of the relevant definition of the exchange rate and estimate a bivariate BEKK model where the A and B matricies are restricted to be diagonal. Maximum likelihood estimation then produced the set of parameter estimates shown in tables 1 and 2, where B11 and B12 are the constant and lagged dependent variable coefficient in the sterling dollar equation and B21 and B22 are the corresponding coefficients in the Euro Dollar equation.

Table 1. The Bivariate Nominal Exchange Rate Model

Var	Coeff	Std. Error	t-Stat
B11	0.236038	0.150359	1.56
B12	1.022842	0.020927	48.87
B21	0.010908	0.121295	0.08
B22	0.991444	0.004780	207.4
A11	0.556973	0.073124	7.61
G11	0.878169	0.031172	28.17
C11	0.000719	0.000245	2.93
C12	0.003493	0.000650	5.35
C22	-0.000622	0.000958	-0.65
A22	0.288860	0.058115	4.97
G22	0.942488	0.016526	57.03

Table 2. The Bivariate Model based on Relative Consumer Prices

Var	Coeff	Std. Error	t-Stat
B11	0.626276	0.253210	2.5
B12	0.942173	0.020272	46.4
B21	0.253396	0.156416	1.6
B22	0.956215	0.012994	73.5
A11	0.142521	0.101197	1.4
G11	0.001000	0.175105	0.0
C11	0.018854	0.001291	14.6
C12	0.011676	0.001640	7.1
C22	0.000003	0.001411	0.0
A22	0.640873	0.166676	3.8
G22	0.576504	0.097145	5.9

The multivariate GARCH process is fairly well determined in both cases. Figures 1 and 2 show the conditional covariance for the two series.

Fig. 1. Covariance of £/$ and €/$ Nominal Exchange Rates

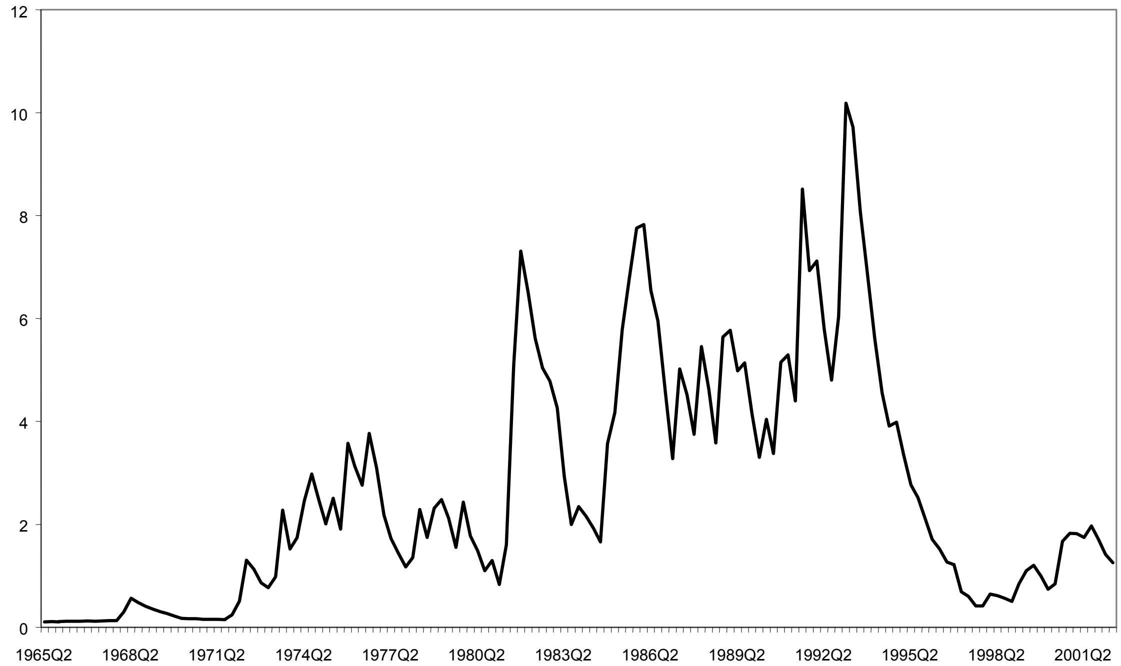
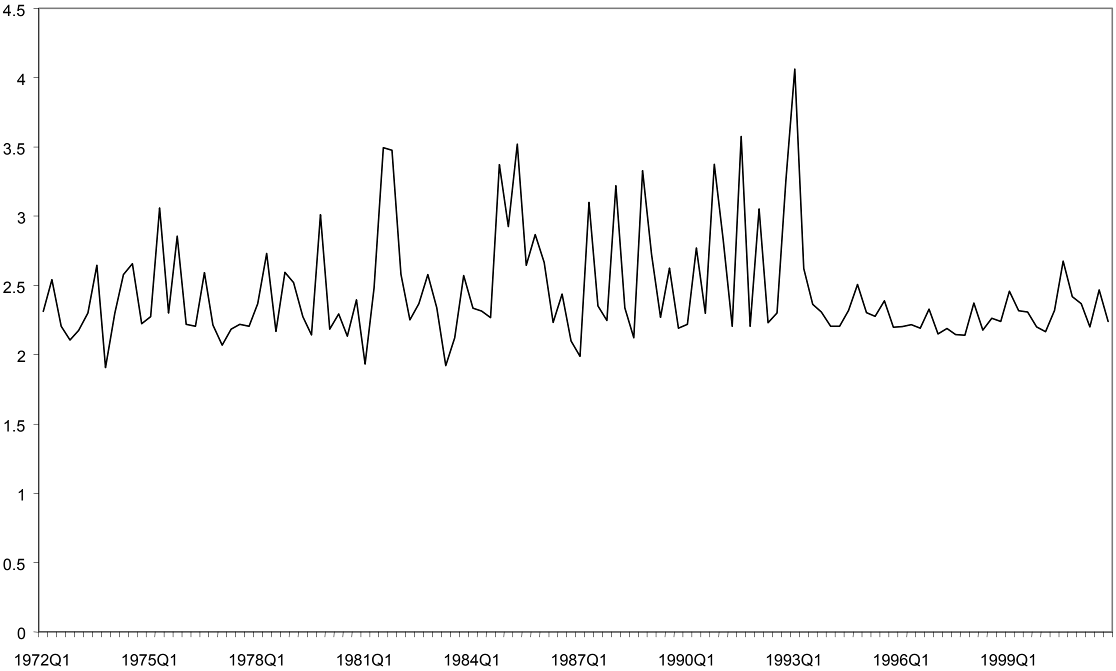


Fig. 2: Covariance of £/$ and €/$ Exchange Rates based on Relative Consumer Prices



3. An Econometric Model of Foreign Direct Investment in R&D

For the empirical investigation of the impact of exchange rate uncertainty on foreign direct investment in R&D in the UK, we use variations of the following model[2]:

$$\Delta\ln(F_{it}) = a_i + \beta_1 \Delta\ln(Y_{it}) + \beta_2 \ln(F_{i,t-1}) + \beta_3 \ln(Y_{i,t-1}) + \beta_4 G_{i,t-1} + \beta_5 D_{i,t} + \beta_6 \ln(I_{i,t-1})$$

$$+ \beta_7 \ln(IM_{i,t-1}) + \gamma_1 COV_{t-1} + \gamma_2 VARSD_{t-1} + \gamma_3 VARED_{t-1} + \gamma_4 \ln(RLC_t) + \gamma_5 LRR_t$$

$$+ \delta \ln(HE_{t-1}) + \varepsilon_{it} \qquad [10]$$

where F_{it} denotes the volume of expenditure on R&D by foreign-owned firms in the UK in industry *i* at time *t*, Y is value-added output in the industry as a proxy for market size, G is the share of R&D undertaken by businesses and funded by the government, D is the share of R&D invested by domestic firms, I denotes net capital expenditure, IM denotes import penetration as a measure for the degree of product market competition in an industry, COV is

[2] This empirical specification takes the general form of many models used in studies of total or domestic R&D in several contexts. See, for example, Bloom *et al* (2002). The error correction type approach we employ is similar to the models estimated in Bond *et al* (1999), Guellec and Ioannidis (1997) or Guellec and van Pottelsberghe (1997).

the GARCH estimate of the covariance between the logarithm of the real or nominal values of the euro dollar exchange rate and the sterling dollar exchange rate resulting from our analysis in section II, VARSD and VARED are the GARCH estimates of the variance of the logarithm of the real or nominal sterling dollar and the real or nominal euro dollar exchange rate, respectively,[3] RLC denotes the UK real effective exchange rate, LRR denotes the real long-term interest rate[4], and HE is R&D performed by higher education. A growing body of evidence indicates that a firm's ability to locate near universities or research centres as well as membership in research joint ventures or cooperations[5] may affect the pattern of R&D across countries and regions. Significant R&D enhancing effects are, for instance, found by Adams *et al* (2001), Adams *et al* (2000), Jaffe (1989), Jaffe *et al* (1993) as well as Acs *et al* (1992). In this context, we attempt to test for the role R&D performed by higher education may play in attracting foreign R&D investment into the UK.

In the light of the possible entry of the UK into European Monetary Union, the coefficient on the covariance term, γ_1, is of major interest to us. If we join monetary union, the correlation of the Pound and the Euro will go to one, the covariance of the Sterling Dollar and the Euro Dollar exchange rates will rise. Statistical significance with a positive sign of γ_1 will therefore imply that UK entry into EMU would increase the UK's attractiveness as a location for foreign direct investment in R&D, while a negative sign would suggest that the UK is enjoying more foreign R&D outside EMU. Significance with a negative sign of γ_2 would indicate an increase in R&D FDI as a result of a reduction in Sterling Dollar exchange rate uncertainty. The sign of γ_3 will allow conclusions to be drawn about the relocation of foreign R&D between the UK and the Euro Area following variations in the volatility of the Euro Dollar exchange rate.

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[3] The quarterly numbers for COV, VARSD and VARED were transformed to annual ones by taking the arithmetic average per year. We use the real values in estimation in order to control for inflation.

[4] The measure of real long-term interest rates we employ uses the current nominal 10 year government bond rate plus a forward-looking convolution of inflation over the next 10 years. Whilst this is equivalent to assuming that the average annual inflation rate over this period was forecast without error, which may be a strong assumption, it does not seem inappropriate to make this assumption as UK price inflation has been broadly stable over the last decade. Data on inflation expectations are partly constructed using the numbers on the NIESR forecast baseline for the UK economy as estimated outturns.

[5] See, for instance, Tirole (1988) or Kamien *et al* (1992) for theoretical literature on the impact of joint ventures and cooperation on R&D spending. Dixit (1985) conducts an anlaysis within the framework of international competition.

The industry-specific fixed effects a_i will control for unobserved heterogeneity between industries. Controlling for small sample bias of the panel estimates due to the inclusion of the lagged dependent variable[6] (Nickell, 1981) requires an instrumental variable estimator. We employ the rank order of the lagged dependent variable, following Durbin (1954), as well as the second lag of ln(F). The rank order has been 'cleaned' of the lagged disturbance term but is clearly highly correlated with the variable being instrumented. In order to eliminate potential simultaneity bias arising from the inclusion of the change in current output and the current domestic R&D term, we treat these variables as endogenous in estimation and instrument them by the first lag of the output change and by the first and second lag of the R&D variable, respectively.

The available data for foreign direct R&D investment and direct government funding restricted the beginning of the sample period of the panel we employ in estimation to 1993.[7] The manufacturing sector is split into 11 broad industries, shown in table 3. Most foreign R&D is invested in the chemicals and the transport industries.

Table 3. Manufacturing Product Groups

Industry Group	SIC(92)
Food, drink and tobacco	15-16
Textiles	17-19
Pulp and paper and publishing	20-22
Chemicals	24
Rubber and Plastics	25
Other non-metallic minerals	26
Metals	27-28
Other Machinery and Equipment	29
Electrical Machinery and Instruments	30-33
Transport Equipment	34-35
Other Manufacturing	36

[6] This will allow us to test for adjustment costs. Theory suggests these are important because of the high cost of temporary hiring and firing of highly qualified labour with firm-specific knowledge, and because a sustained commitment to R&D is often required for projects to be successful. For empirical evidence, see Bernstein and Nadiri (1986), Hall *et al* (1986) and Himmelberg and Petersen (1994). Hall (1993) reports that at least 50 per cent of R&D budgets typically consist of the salaries of professional scientists and engineers.

[7] Detailed information on the data and their sources can be found in the data appendix.

4. Empirical Results

All regressions are estimated by the generalized methods of moments, following Arellano and Bond (1991). The validity of the instrument sets is tested using a Sargan test of overidentifying restrictions which is easily accepted in all regressions. Hence our model specifications pass a key diagnostic test.

The results of estimating [10] in its most general form are presented in table 4, column (1). We cannot reject the hypothesis that the coefficient of R&D performed by higher education is equal to zero. This may not be surprising in the light of the fact that data for this variable were only available at the country aggregate, whilst it is likely that this measure of R&D varies considerably between industries. University research laboratories, for instance, are likely to conduct a substantial amount of R&D in high-tech sectors such as chemicals or aerospace, but only little in very low-tech industries such as textiles. Since, then, this variable is not a genuine macroeconomic variable that would vary only over time, we first restrict δ to be zero. Sequentially nesting our model down further this way, we obtain the more parsimonious specification (2), restricting δ and γ_2 to zero.

We find that the covariance between the sterling dollar exchange rate and the euro dollar exchange rate is a significant determinant of the location of foreign R&D in the UK. An increase in the covariance, which we will see if the UK enters European Monetary Union, will tend to raise foreign direct R&D investment in the UK. In the light of the fact that foreign investment in R&D accounts for a significant amount of total R&D in the UK, over a third in manufacturing in the late 1990's for example, coupled with the beneficial effect of R&D on economic growth, these results suggest that the UK would benefit from adopting the single currency.

We experimented with a range of alternative sets of instruments and found this result to be robust. Column 3 in table 4 reports the estimation results of our preferred specification, which uses the average annual yield on 2011-dated UK index-linked government securities as an instrument for the constructed real interest rate. Here we follow Pagan (1984) who showed that the variance of a generated regressor is likely to be lower than that of the true unobserved series so that it should be instrumented in estimation in order to avoid biased estimates of the standard errors. Inspection of the results reveals that the evidence in (3) generally confirms that obtained in (2).[8]

While FDI in R&D is not found to be significantly sensitive to changes in the volatility of the sterling dollar exchange rate, which has therefore been excluded from the model, the variance of the euro dollar exchange does appear to play a significant role in attracting foreign R&D into the UK. The evidence suggests that an increase in the volatility of this exchange rate tends to relocate R&D investment from the Euro Area into the UK. This result and that found for the covariance lead us to conclude that risk diversification of multinational firms appears to be an important determinant of foreign direct investment in R&D in the UK.

An appreciation in the UK real effective exchange rate is found to depress the volume of foreign R&D investment. Increases in real long-term interest rates also appear to have a large significant adverse impact. The long-run decline of inward R&D FDI as a result of a sustained rise of interest rates of 1 percentage point, a change which is unlikely to be observed often, is estimated to amount to 11.4%. We also tested for an impact of the real UK and Euro Area interest rate differential, but this was not found to be significant.

Inward FDI in R&D is procyclical from a UK perspective in the short term. The output effect is robust to the inclusion of time dummies in regression [4][9]. Output fluctuations are thus a highly significant determinant of inward FDI in R&D over and above any macroeconomic variation they may be picking up in [3]. Furthermore, the standard errors of the regression including the time dummies and the regressions including the four macroeconomic factors are essentially the same. This suggests that our macroeconomic variables account for most of the macroeconomic variation that might have an effect on inward FDI in R&D. Including the three remaining[10] time dummies in [3] seems to support this conclusion, as a Wald test of joint insignificance of the dummies cannot reject their exclusion [Chi-squared(3)=6.08]. The output results for the longer run suggest that, ceteris paribus, foreign expenditure on R&D will rise in line with output. The long-run elasticity is 0.7, and as one would expect we could not reject the hypothesis of a unit elasticity on the basis of a Wald test [Chi-squared(1)=0.81].

[8] The long-run effects reported in the following therefore refer to regression [3].
[9] In this regression, we replace the macroeconomic factors by time dummies.

[10] Five time dummy variables are excluded from the regression due to the constant term and the four macroeconomic variables.

Government funding appears to play an important role in attracting foreign direct investment in R&D into the UK. The results suggest that a permanent increase of 1 percentage point in the share of business R&D funded by the government will increase the volume of foreign R&D investment by 1.6%. Firms which experience some external financial constraints may aim to take advantage of direct government support that may be relatively more generous in certain industries in the UK and that will allow them to sustain higher R&D spending. The decline of 4.8 percentage points in the share of manufacturing R&D financed by the government between 1992 and 1997 will thus have had a dampening impact on the pace of expansion of foreign R&D investment in the UK during the 1990s.[11]

Our results also suggest that an increase in the share of R&D undertaken by indigenous firms may on average crowd out foreign R&D investment. Some multinationals may see a relatively smaller presence of foreign-owned firms conducting R&D as a signal that the potential for R&D related knowledge spillovers is smaller. For a sample of UK regions, Cantwell and Immarino (2000) for example provide some evidence that the South East, which they identify as the UK's core region of technological expertise, attracts foreign-owned firms' research for reasons other than its existing indigenous technological specialisation.

We also tested for the existence of externality effects from total net capital investment on foreign R&D investment. The evidence indicates that higher capital spending by businesses is of significant importance for increasing the foreign R&D base in the UK, with an estimated long-run elasticity of just below 0.2 per cent. Higher capital investment may be seen as an indicator of institutional conditions favourable to investment in general. There is only little evidence that an increase in domestic market competition as measured by the import penetration ratio tends to be taken into account in multinationals' decision to locate R&D investment in the UK. Finally, the highly significant negative coefficient of the lagged dependent variable indicates that there may be large adjustment costs associated with foreign R&D.

[11] The results with respect to the effect of direct government funding on multinationals' choice on the location of foreign investment in R&D are similar to those found in the cross-country analysis of eight OECD countries by Bloom and Griffith (2001). They provide evidence that R&D in one country responds to a change in the R&D tax credit in another country.

Real expenditure on R&D and output are potentially non-stationary $I(1)$ series. However, as we cannot reject H_0 of no first- and second-order autocorrelation in the regressions, we can conclude that the error terms are stationary, and we are thus able to rule out the possibility of bias due to spurious correlations.

Table 4. Panel Data Results For Foreign Direct Investment in Industry R&D

Dependent Variable: $\Delta\ln(F_{it})$; Sample Period 1993-2000

	[1]	[2]	[3]	[4]
$\Delta\ln(Y_{i,t})$	1.8963 (3.6)	2.3889 (4.8)	2.2939 (5.2)	1.5462 (4.3)
$\ln(F_{i,t-1})$	-0.8407 (17.8)	-0.8593 (16.7)	-0.8559 (17.1)	-0.8568 (18.0)
$\ln(Y_{i,t-1})$	0.7132 (3.8)	0.6298 (2.4)	0.6346 (2.5)	0.7133 (5.0)
$G_{i,t-1}$	0.0117 (2.1)	0.0136 (2.0)	0.0134 (2.0)	0.0109 (2.1)
$D_{i,,t}$	-0.0360 (14.3)	-0.0365 (14.7)	-0.0358 (15.0)	-0.0369 (13.3)
$\ln(I_{i,t-1})$	0.1141 (1.7)	0.1572 (2.4)	0.1524 (2.3)	0.1526 (1.9)
$\ln(IM_{i,t-1})$	0.4120 (1.7)	0.3169 (1.5)	0.3168 (1.6)	0.5030 (2.0)
Real interest rate $_t$	-0.0893 (3.2)	-0.0939 (3.2)	-0.0979 (3.4)	
ln(Real exchange rate $_t$)	-0.6112 (2.0)	-0.7583 (2.5)	-0.7895 (2.6)	
COV $_{t-1}$	0.0285 (0.2)	0.1821 (2.2)	0.1942 (2.4)	
VARSD $_{t-1}$	0.0051 (0.5)			
VARED $_{t-1}$	0.5880 (1.2)	0.5956 (2.4)	0.5496 (2.2)	
ln(HE $_{t-1}$)	-0.5400 (1.4)			
No. of observations	88	88	88	88
Standard error	11.5%	11.7%	11.7%	11.4%
Sargan (p-value)	0.337	0.424	0.410	0.295
AR(1)	-0.618	-0.535	-0.576	-0.485
AR(2)	0.705	0.474	0.431	0.698

Note: T-statistics in parentheses are based on robust standard errors. Estimation is by GMM. The regressions include dummies in order to account for outlying observations. Regression [3] uses the index-linked bond yield as an instrument for the constructed real interest rate. Regression [4] includes a full set of time dummies, so that the macroeconomic variables are excluded from the regression. The dummy for the first year of the sample period is excluded because of the constant term. Each time dummy is individually significant at the 1% level of significance except for that for the year 1994, which is significant at the 10% level.
'Sargan' is a Sargan test of the overidentifying restrictions. AR(1) and AR(2) are tests of first- and second-order serial correlation. They are distributed $N(0,1)$ under the Null.

Since data for R&D performed by higher education were only available for the country aggregate, this did not allow us to draw conclusions about the role industrial R&D performed by higher education may play in attracting foreign R&D investment into the UK. However, in order to get some idea about the potential impact of R&D performed by higher education, we estimated two additional regressions where we assumed R&D by higher education was only performed in the two most high-tech industries, chemicals and transport (regression 5 in table 5), or in the two industries that were least R&D intensive during the period 1993-2000 on average, other manufacturing and textiles (regression 6). For all other industries, the observations were set to zero. The results provide some indication that, ceteris paribus, an increase in R&D performed by higher education may help to attract foreign high-tech R&D into the UK. The two dummy-like variables for the low-tech industries however either have a negative sign or are not significant at conventional levels. The inclusion of the constructed measure of R&D performed by higher education in the two low-tech industries serves to reduce the sign and significance of the coefficient of the covariance term, while the variance of the euro dollar exchange rate increases. This may indicate that the UK's entry into monetary union is likely to affect high- and low-tech foreign R&D in significantly different ways. Furthermore, the coefficient of the government funding variable becomes insignificant. This might suggest that R&D performed by higher education in low-tech sectors relies more on government funding than that in high-tech industries, so that a significant increase in higher educational R&D may be associated with a shift of government support from direct funding of R&D to higher education R&D. In some industries, this may have an adverse net effect on foreign expenditure on R&D in the UK, if government funding is sufficiently more effective in providing an incentive for the location of foreign R&D in low-tech sectors than is R&D performed by higher education. However, these results should be interpreted merely as a hint at significant differences of this kind between industries. A rigorous sector-specific analysis of the factors underlying multinationals' choice of the location of their R&D activity in the UK will require a split of the whole sample into a high-tech and a low-tech subsample. This is one of our avenues for further research.

Table 5. Panel Data Results For Foreign Direct Investment in Industry R&D Including a Proxy for Spillovers from R&D Performed by Higher Education

Dependent Variable: $\Delta\ln(F_{it})$; Sample Period 1993-2000

	[5]	[6]
$\Delta\ln(Y_{i,t})$	2.0778 (6.4)	2.1479 (4.8)
$\ln(F_{i,t-1})$	-0.8901 (19.2)	-0.8723 (18.9)
$\ln(Y_{i,t-1})$	0.5304 (3.4)	0.8162 (2.6)
$G_{i,t-1}$	0.0167 (2.3)	0.0109 (1.6)
$D_{i,,t}$	-0.0349 (19.6)	-0.0392 (17.1)
$\ln(I_{i,t-1})$	0.1295 (1.7)	0.1164 (1.6)
$\ln(IM_{i,t-1})$	0.1015 (0.5)	0.2186 (1.2)
Real interest rate $_t$	-0.0992 (3.4)	-0.0890 (3.4)
ln(Real exchange rate $_t$)	-0.8318 (2.7)	-0.7042 (2.7)
COV_{t-1}	0.2511 (3.4)	0.1831 (2.2)
$VARED_{t-1}$	0.4071 (1.6)	0.5357 (2.4)
$\ln(HEDG_{t-1})$	1.3443 (6.3)	
$\ln(HEDM_{t-1})$	1.7532 (6.9)	
$\ln(HEDBC_{t-1})$		1.1360 (1.9)
$\ln(HEDN_{t-1})$		-1.2114 (4.6)
No. of observations	88	88
Standard error	10.5%	11.4%
Sargan (p-value)	0.633	0.406
AR(1)	-1.571	-1.276
AR(2)	0.031	-0.454

Note: T-statistics in parentheses are based on robust standard errors. For further notes see table 4

The results presented in table 4 allowed us to draw the conclusion that our macroeconomic factors account for most of the macroeconomic variation that might have an effect on inward FDI in R&D. The results further suggest that none of the factors has a principal impact that would account for most of the economy-wide effects alone, i.e. that there is no principal macroeconomic driving force behind the pattern of variation between foreign direct R&D investment in different manufacturing industries. In order to corroborate this result, we test for a common trend by means of a principal components analysis (Harman, 1976). The major results are presented in table 6. Whilst they do indicate non-stationarity of the first principal component and stationarity of all other components, supporting the hypothesis of one overall trend, the variation accounted for by the first principal component is only 43-45% over the two periods 1991-2000 and 1993-2000. Explaining around 90% of the pattern of correlation between foreign R&D expenditure in the 11 manufacturing industries requires the cumulative explanatory power of the first four components. These results indicate that there is not one common factor that accounts for most of the variation in foreign R&D investment across industries.

Table 6. Results of Principal Components Analysis of Industrial Foreign Direct R&D Investment

Period	1993-2000		1991-2000	
Component	Eigenvalue	Cumulative R-Squared	Eigenvalue	Cumulative R-Squared
1	4.9145	0.4468	4.7263	0.4297
2	2.1971	0.6465	2.3110	0.6397
3	1.6774	0.7990	1.6002	0.7852
4	1.1980	0.9079	1.2692	0.9010
5	0.5343	0.9565	0.5725	0.9526
6	0.3611	0.9893	0.4220	0.9910
7	0.0754	0.9962	0.0099	1.0000
8	0.0370	0.9995	0.0000	1.0000
9	0.0052	1.0000	-0.0000	1.0000
10			-0.0000	1.0000
11			-0.0000	1.0000

5. Conclusions

In this paper we have sought to investigate the role exchange rate uncertainty is likely to play in multinational firms' decisions to locate foreign direct R&D investment in the UK. The literature on uncertainty and investment to date offers little or no evidence on this question. We also extend the existing analyses from the current practise of simply considering the volatility of exchange rates to also considering the covariance between exchange rates. We believe that this is particularly important in the light of the possible entry of the UK into European Monetary Union. In general entry may not mean an overall reduction in exchange rate volatility, but the one thing that we are certain of is that if we join monetary union the correlation of the Pound and the Euro will go to one, and the covariances must increase.

We present a theoretical framework that demonstrates that risk-averse firms benefit from FDI diversification and generate GARCH estimates of the conditional covariance and the conditional correlation between the dollar sterling and the dollar euro exchange rates. We then estimate an econometric model of foreign direct investment in R&D, using a panel of 11 UK manufacturing industries. Our results suggest that an increase in the volatility of the euro dollar exchange rate tends to relocate R&D investment from the Euro Area to the UK. With respect to the UK's entry into EMU, we find that an increase in the covariance between the sterling dollar and the euro dollar exchange rate will tend to relocate foreign direct R&D investment into the UK. Other factors identified to have significant effects are real long-term interest rates, output fluctuations, net capital expenditure and the proportion of business R&D conducted by businesses and funded by the government.

Data Appendix

This Appendix gives a brief description of the data used in the empirical work and their main statistical source.[12] For two-digit SIC(92) industry coverage, see text.

R&D series:

All data have been converted from the Office for National Statistics (ONS) R&D product group (PG) codes to SIC(92) using a concordance provided by the ONS. Data were taken from ONS MA14 or the ONS website where available. According to information from the ONS, MA14 editions with detailed industry data exist only for 1989 and 1993-2000. Data for total R&D (variable R) and for selected other series totals (sum of all PG's) are published in revised form on the ONS website, including the years 1990-1992.

R – expenditure on R&D performed in UK businesses, ONS website.

G – expenditure on R&D performed in UK businesses and funded by the government (GOVT) as a share of R. Data for GOVT series total were taken from ONS website for each year. GOVT at detailed PG level is not available in revised form for 1993-1998 and not available at all for 1991 and 1992. Data for 1993-1998 were collected from ONS MA14, various editions. The data for 1993-1995 was converted from 1993 to 1996 PGs using conversion factors based upon R, the only series for which data in the old and the new form are available for all relevant years. For nine out of twenty PGs, the conversion factor was 1. In absence of any information to the contrary, pre-1993 data at the detailed PG level were then obtained by applying 1993 PG shares in the series total to the revised series totals of the relevant years. In order to match 1999 data revisions, we revised 1993-1998 data at the detailed PG level in a similar way, using the respective shares in each year.

F – expenditure on R&D performed in UK businesses by foreign-owned firms. Revised data for 1993-1999 provided by the ONS. Pre-1993 data were not available either for the series total or at the detailed PG level. The series total for those years was thus interpolated using information on foreign funding of business R&D. Data at individual PG level were then obtained as for GOVT.

D - expenditure on R&D performed in UK businesses by indigenous firms (UK) as a share of R. Revised data for 1993-1999 provided by the ONS. For the earlier years, UK was obtained as R minus FOREIGN.

HE – UK-wide expenditure on R&D performed by higher education, ONS MA14.

Non-R&D series:

Y – gross value added, 1995 prices, ONS Blue Book (website).

I – total net capital expenditure. Data for 1995-1999 from ONS Annual Business Inquiry (website), linked to equivalent series in ONS Census of Production Summary Volume PA1002, various editions, for the earlier years. Pre-1993 data were converted from SIC(80) to SIC(92) using an unpublished concordance as in Hubert and Pain (2001).

[12] Much of the data we use are taken from the dataset constructed for use in Becker and Pain (2003).

IM – import penetration ratio, calculated as value of imports over home demand. Trade data from ONS MQ10 (website). Turnover data obtained as for total net capital expenditure.

Real effective exchange rate - January 2002 NIESR forecast base.

Real long-term interest rate – January 2002 NIESR forecast base, see text for details.

GILT – average annual yield on UK index-linked government securities.

Nominal series were deflated using the gross value added deflator, 1995=100, as obtained from gross value added at constant and at current prices, ONS Blue Book. Nominal R&D performed by higher education in the UK as a whole was deflated by the GDP deflator, January 2002 NIESR forecast base.

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