INVESTMENT AND UNCERTAINTY IN THE G7

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1. Introduction

The benefits of macroeconomic stability are increasingly emphasised by policy makers. This has followed but also underpinned a growing academic interest in economic uncertainty and its effects on macroeconomic variables. Output growth in both the short and long run is crucially dependent upon aggregate business investment and the focus of this paper is the relationship between investment and uncertainty. The two main strands of theoretical literature on this relationship come to different conclusions. The call option approach to investment determination (Dixit and Pindyck 1994), implies that increased uncertainty reduces investment given the irreversibility of investment projects and the consequent option value of delaying expenditures. In contrast, earlier work (Hartman (1972), Abel (1983)) suggested that increased uncertainty raises investment where the marginal product of capital is an increasing function of prices and increases in the variance of prices will increase the expected return. Given this theoretical dispute there is a need for empirical analysis.

While there is an extensive empirical literature on uncertainty and investment,[1] it is mainly undertaken on the basis of one country or one indicator of uncertainty. Carruth et al. (2000b) are of the view that the broad consensus is that the relationship is negative and this consensus emerges from a wide range of models and alternative methods of proxying uncertainty. On the other hand, Huizinga (1993) suggests that effects vary depending on the source of uncertainty. Furthermore, differing results for a single indicator such as exchange rate volatility have been found by authors such as Goldberg (1993) and Darby, Hughes Hallett, Ireland and Piscittelli (1999) depending on the countries studied, methods of deriving measures of uncertainty and the data period used. In this paper we argue that there are good reasons for using conditional volatility measures such as those derived from GARCH estimation as the best measures of uncertainty in a forward looking sense.

Recently, non-stationary panel econometric methods have become popular in multi-country macroeconomic studies. These methods, which have both a time series and cross sectional dimension, are a means of increasing the efficiency of parameter estimates when testing a particular long run hypothesis whilst taking account of potential non-stationarity. While some differences across countries are to be expected, when adopting this approach it is important to test for cross sectional heterogeneity to ensure that panel estimates are not biased due to "unreasonable" pooling of countries, see Pesaran and Smith (1995). Taking account of these factors, we conduct a multi-country study of investment and a comprehensive range of macroeconomic indicators of uncertainty using Pesaran, Shin and Smith's (1999) Pooled Mean Group Estimation (PMGE), and GARCH methods to derive uncertainty measures. We assess long term effects on investment of measures of conditional volatility, and short term dynamic effects of our uncertainty proxies on investment, while paying particular attention to whether long run country homogeneity is accepted by the data. The indicators used include both financial variables (equity prices, interest rates and exchange rates), and macroeconomic variables, (inflation and industrial production).

We come to the conclusion that the source of volatility typically does matter, with exchange rate volatility being most crucial. Besides the general interest in such work, the effect of uncertainty on investment is an important aspect of the benefits of EMU membership, since EMU is likely to remove part of effective exchange rate volatility and, possibly, part of long rate volatility also. The paper is structured as follows. In Section 2 we provide a brief overview of the theoretical and empirical literature on uncertainty and investment. In Section 3 we address specification and estimation issues. In Section 4 we set out the data, Section 5 considers results whilst Section 6 draws conclusions.

2. Literature Survey

2.1 Theory of Investment and Effects of Uncertainty

According to Dixit and Pindyck (1994), the effect of uncertainty on investment stems from the option characteristics of an investment project, given the option of delaying the project and its

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[1] See the excellent review by Carruth, Dickerson and Henley (2000b).

irreversibility once begun, together with the uncertainty over future prices that will determine its profitability. The value of the option stems from the fact that delaying the project may give a more accurate view of market conditions. The call option implies a difference between the net present value (NPV) of an investment and its current worth to the investor. To lead to expenditure, the NPV has to exceed zero so as to cover the option value of waiting. The expectation is that heightened uncertainty, by leading to delay in projects, would lead to a fall in aggregate investment. There may also be threshold effects i.e. rates of return below which investment is not undertaken, depending on investors' risk aversion. Abel et al. (1996) extended this theory of irreversibility to show that there could be both a call and put option feature in investment, in terms of options to expand or contract the capital stock in the future.

The literature is not unanimous in suggesting a negative effect of uncertainty on investment. Hartman (1972) and Abel (1983) show counter to the above that where there is perfect competition and constant returns to scale as well as symmetric adjustment costs, an increase in uncertainty may also raise the value of a marginal unit of capital and hence the incentive to invest. Lee and Shin (2000) argue that the balance between the positive and negative effects of uncertainty may depend on the labour share of firms' costs.

Given these contrasting theoretical results, as well as ambiguity as to where uncertainty originates at a macro level, empirical work is vital. We now go on to review empirical methods and studies in terms of sources of uncertainty and their use in investment functions, before undertaking our own empirical work.

2.2 Empirical work on Investment and Uncertainty

An extensive survey of the empirical literature on investment and uncertainty is provided in Carruth et al. (2000b). Overall, they suggest there is a broad consensus that the effect from proxy measures of uncertainty on aggregate investment is negative. This is for a wide range of models and various methods of proxying uncertainty. Our intention is not to repeat that survey, but rather to provide a thematic overview giving sufficient background for understanding our results and possible contrasts with earlier studies, as well as to reference more recent work.

First, there are issues in choosing the *source of uncertainty* where there are often conflicting theoretical arguments. Taking the example of share price volatility, it is argued in Carruth et al. (2000b) that use of stock market based measures may reveal cash flow uncertainty for the firm, but are not relevant indicators of future economic shocks and policy changes. Moreover, stock prices may be vulnerable to bubbles rather than reflecting fundamentals. Hence they argue that macroeconomic variables such as price, output and exchange rate volatility are often preferred instead. One could query this approach since share prices take into account all information relevant to the future profitability of the firm (or at a macro level the corporate sector). Furthermore, one can argue that investment is discounted by the long rate plus a risk premium, where the latter may be linked to equity market volatility (Davis and Madsen, 2001). Such conflicting views suggest a need to take a comprehensive empirical view of possible measures and their impact.

As regards *measurement of uncertainty*, authors that have used ARCH or GARCH measures of macroeconomic variables when modelling investment include Huizinga (1993) and Price (1995). Huizinga (1993) considers conditional volatility of US inflation, real wages and real profits and generally finds a negative effect on investment. Price (1995) utilises the conditional variance of the growth rate of GDP, and finds a negative effect on UK manufacturing investment lagged twice. The question of whether there is a different effect from forward and backward looking measures of uncertainty has been raised by Ferderer (1993). He attempts to produce a forward looking measure based on the risk premium from the term structure. For the US he finds that the effect on investment is negative. Driver and Moreton (1991) model uncertainty using the standard deviation of 12 months forward predictions of output growth and inflation across 12 forecasting teams. They find a negative long-run effect from output growth on investment but no long-run effect from inflation on investment. Goldberg (1993) and Campa and Goldberg (1995) derived their measure of exchange rate volatility from the standard errors of the residuals from a moving average representation of the exchange rate using US data.

Looking specifically at *exchange rate volatility and investment*, Darby et al. (1999) using a model based on Dixit and Pindyck (1994) suggest that there are situations where exchange rate uncertainty will depress investment and situations where it will not. In the empirical section of their paper Darby et al. (1999) find, using a neoclassical model, Tobin's Q and moving average exchange rate variance, that uncertainty has a significant and negative impact on investment for the US, Germany and France. There are additional dynamic effects which are negative for Italy and the UK. There are negative misalignment effects for US, France, Italy and the UK.

Serven (2003) using GARCH measures of uncertainty, finds a negative and highly significant impact of real exchange rate uncertainty on private investment in a sample of developing countries, after controlling for standard investment determinants. The impact is larger at higher levels of uncertainty – in line with the analytical literature underscoring 'threshold effects'. Moreover, the effect on investment of real exchange rate uncertainty is shaped by the degree of trade openness and financial development: higher openness and weaker financial systems are associated with a more significantly negative uncertainty- investment link.[2]

We suggest that there are a number of lacunae in the existing macro literature, that we shall seek to fill in the following sections. Studies tend to be for a single country, indicator and measurement method. Unlike many studies cited above, we look both across a range of indicators and also utilise a panel methodology for the G7 countries, testing for homogeneity in long run responses across countries. We now go on to describe our approach to estimating the relationship between investment and uncertainty.

3. Specification and Estimation Issues

3.1 Measures of Uncertainty

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[2] Some disaggregate studies, including Leahy and Whited (1996), Driver et al. (1996), Guiso and Parigi (1999) and Temple et al. (2001) also found negative effects of uncertainty on investment in at least some industries. For example

As noted above, in empirical applications, uncertainty is typically proxied by measures of volatility. This section provides a brief discussion of such measures. We conclude the section with arguments which favour conditional volatility measures such as GARCH, against moving average standard deviations.

In the GARCH(p,q) model introduced by Bollerslev (1986) we consider the information set Y_{t-1}, which contains all information on the variable y_t until time t-1. Also we assume the time series y_t can be described as

$$y_t \mid Y_{t-1} = (h_t)^{\frac{1}{2}} \eta_t, \qquad \eta_t \sim NID(0,1) \tag{1}$$

$$h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i y_{t-1}^2 + \sum_{i=1}^{p} \beta_i h_{t-1} \tag{2}$$

Where h_t is the conditional variance.[3] Given a coefficient on the lagged squared error α_1 greater than zero, volatility will tend to cluster, with large residuals following other large residuals, but of unpredictable sign, while a random, normally-distributed variation in the conditional distribution (error variance) gives the unconditional distribution (error distribution) fatter tails than the normal distribution.[4]

Most of the GARCH studies in the literature, for stock returns, the term structure or exchange rates, have found a significant degree of both short and long run shock persistence with high frequency data, thus accounting for the clustering of volatility which is characteristic of such markets (Bollerslev et al. 1992). Studies of inflation have found similar results (Engel, 1983). There are numerous variants on the basic GARCH which allow inter alia for a distinction between short and long run volatility (components GARCH) and asymmetries in effects of volatility (exponential GARCH). Given our focus here is on testing a range of indicators, we retain

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Temple et al. (2001) found that UK industrial survey responses suggested external finance constraints and uncertainty about demand were factors limiting investment, but that the former depended on concentration in the industry.

[3] To ensure a well-defined process, all the parameters in the infinite order AR representation must be non-negative, where it is assumed that the roots of the polynomial lie outside the unit circle. For a GARCH(1,1), a sufficient lag length in most applications according to Bollerslev et al. (1992), this amounts to ensuring that both α_1 and β_1 are non-negative. It follows also that y_t is covariance stationary if and only if $\alpha_1 + \beta_1 < 1$.

[4] Using the coefficient β_1 on the lagged dependent variable and setting the conditional variance constant, GARCH enables a long run response of the conditional variance to shocks to be calculated. $\alpha_0/[1 - \alpha_1 - \beta_1]$ is the mean level of volatility.

GARCH (1,1) – in further work on exchange rate volatility (Byrne and Davis 2003a) we set out complementary results using these alternative approaches. We maintain that they do not controvert the basic results presented here.

An alternative to the use of GARCH or variants are types of moving average standard deviations or variances of the series in question. One such measure of volatility based on the variance was adopted by Kenen and Rodrick (1986) and Darby et al. (1999)

$$KR = \left[\frac{1}{8}\sum_{i=1}^{8}\left(\Delta \ln e_{t-i}\right)^{2}\right]^{\frac{1}{2}} \qquad (3)$$

Volatility can also be derived using an autoregressive moving average model, the proxy being the standard deviation of the model's residuals, as in Goldberg (1993) and subsequent papers:

$$ER_t = \alpha_1 ER_{t-1} + \varepsilon_t + \beta_1 \varepsilon_{t-1} \qquad (4)$$

Some authors such as Pindyck and Solimano (1993) also work with the moving average standard deviation (SD) of the relevant time series.

We argue that the distinction between GARCH (which measures conditional volatility) and moving average based volatility (a measure of unconditional volatility) is a potentially important one, and that the shows offers more of the theoretical characteristics of uncertainty than an unconditional measure would. To motivate this, consider the distinction originally due to Knight (1921) between risk and uncertainty. Risk can be defined as the danger that a certain contingency will occur, a measure often related to future events susceptible to being reduced to objective probabilities, while uncertainty is a term applied to expectations of a future event to which probability analysis cannot be applied, such as a change in policy regime or a financial crisis (Shafer, 1986). The response of an uncertain market – and the response of investment thereto - may appear out of scale with the proximate causes of a given stimulus, if it leads participants to change the way they form their decisions.

In this context, heightened unconditional volatility alone may merely reflect a greater incidence of large random and independent shocks, i.e. greater *risk*, without a change in underlying perceptions as to the situation on the part of firms considering investment. On the other hand, heightened conditional volatility, besides indicating risk, may also indicate greater (unmeasurable) *uncertainty* on the part of the market regarding the direction of the variable and the intentions of the authorities, including market responses to shocks per se[5] (an increased *tendency* for shocks to have persistent effects on the market) which may be more likely to affect investment. More generally, conditional volatility highlights periods of concentrated volatility which might be expected to maximise uncertainty and hence the option value of waiting to undertake investment, while the rolling measures could just be capturing background volatility with occasional outliers that firms learn to live with. A similar point is made by Serven (2003), who considers use of GARCH essential to measure exchange rate uncertainty as opposed to "sample variability".

3.2 Specification of Investment Functions

We follow Bean (1981), Driver and Moreton (1991) and Darby et al. (1999) in estimating dynamic error correction models of investment including both short and long-run terms in output, investment, *average Q* and the real user cost of capital. Consistent with these authors, we test for long run homogeneity of output as implied by the CES production function. As background we briefly introduce empirical investment models, including the flexible accelerator model, the neoclassical model and Tobin's Q theory of investment (Caballero, 1999, provides a comprehensive survey of the investment literature). The flexible accelerator model is represented by the short and long run relationship between investment and output, such that a desired output capital relationship is maintained. This ignores, however, possible substitution effects between factor inputs, unlike the neoclassical model of Jorgensen (1963). To take account of possible substitution effects the neoclassical model incorporates factor prices in the form of the user cost of capital (C_t). Hence the desired capital stock (K_t*) is as follows

$$K_t^* = \frac{\alpha Y_t}{C_t^{\sigma}} \qquad (5)$$

[5] See also Kurz and Motolese (2001).

where Y is output, α is a constant and σ is the elasticity of substitution between factor inputs.

As discussed in Carruth et al. (2000a), empirical investigators typically assume either that net investment is determined as a distributed lag process of changes in the desired capital stock, or that there are explicit costs of adjustment. Then, it is possible to obtain an investment function for empirical estimation that equates the level of investment to lags of the change in the level of output and the user cost of capital. This is illustrated in the following four equations, where equations (6) and (7) show the evolution of investment in terms of the capital stock, (where δ is the depreciation rate and g is the steady state growth rate), (8) integrates this into equation (5) and (9) sets out the equation in logarithmic form.

$$I_t = \delta K_t + dK_t \qquad (6)$$

$$I_t = (g + \delta)K_t \qquad (7)$$

$$I_t = \alpha(g + \delta)Y_t / C_t^{\sigma} \qquad (8)$$

$$\ln(I_t) = \theta_0 + \theta_1 \ln(Y_t) - \varepsilon \ln(C_t) \qquad (9)$$

A third approach often emphasised in the theoretical investment literature was introduced by Tobin (1969) and highlights the importance of the stock market valuation of the firm relative to the capital stock, or Q as opposed to factor prices. Where capital markets are perfect, there is the implicit assumption that market value will incorporate information on market conditions, for example, uncertainty of costs or final prices. Accordingly, we test for Tobin's Q effects as a variant when assessing the impact of uncertainty on investment.[6,7]

3.3 Econometric Approach

Turning to our estimation approach, panel methods have become popular in cross sectional macro data sets since they provide a greater and more varied information set, and hence

[6] We use the ratio of the capitalised financial value of the firm to the replacement cost of capital or average Q. This is equivalent to the theoretically-appropriate but unobservable marginal Q subject to the production and adjustment cost functions adhering to certain homogeneity conditions (implying inter alia that there is no market power).

greater efficiency, than individual country studies. There are two traditional methods for estimating panel models: averaging and pooling. The former involves running N separate regressions and calculating coefficient means (see for example the Mean Group Estimator method advanced by Pesaran and Smith, 1995). A drawback to averaging is that it does not account for the fact that certain parameters may be equal over cross sections. Alternatively we could pool the data and assume that the slope coefficients and error variances are identical. However, whereas there may be theoretical and empirical reasons to presume that the long-run coefficients are homogenous over the cross-section, there are very few practical cases in which the short-run dynamics and error variances would be homogeneous too. For example, in the case of investment, it can be argued that differences in industrial and trade structure such as exists between the G7 would be likely to affect the short run rather than long run responses to uncertainty (given e.g. their effects on the optimal life of capital goods). We would more generally argue that the PMG approach may be seen in the investment function as modeling the supply side, whereby firms have similar long term reactions to economic variables, given a common objective of profit maximization in the long term, while in the shorter term institutions may play a role (such as scope of liquidity provided by relationship banking) leading to differing dynamics. We note that globalization and growth of multinationals makes a common long run response to volatility plausible (although in the case of exchange rates multinationals might also be sensitive to covariances between bilateral exchange rates).

Following this point, we consider it appropriate to use the Pesaran, Shin and Smith (1999) Pooled Mean Group (PMGE) method, which is an intermediate case between the averaging and pooling methods of estimation and involves aspects of both. The method restricts the long-run coefficients to be equal over the cross-sections, but allows for the short-run coefficients and error variances to differ across cross-sections. We can therefore obtain pooled long-run coefficients and averaged short run error correction dynamics as an indication of mean reversion.

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[7] See Sensenbrenner (1991), Cuthbertson and Gasparro (1995) and Cooper and Ejarque (2001) for evidence on the usefulness of Tobin's Q in empirical modelling. In particular, Cuthbertson and Gasparro find that although Q is

The PMGE is based on an Autoregressive Distributive Lag *ARDL(p,q,…,q)* model

$$y_{it} = \sum_{j=1}^{p} \lambda_{ij} y_{it-j} + \sum_{j=0}^{q} \delta_{ij}' \mathbf{x}_{it-j} + \mu_i + \varepsilon_{it} \tag{10}$$

where $\mathbf{x}_{it}$ $(k\times1)$ is the vector of explanatory variables for group i, μ_i represents the fixed effects, the coefficients of the lagged dependent variables (λ_{ij}) are scalars and δ_{ij} are $(k\times1)$ coefficient vectors. T must be large enough so that the model can be estimated for each cross section.

Equation (10) can be re-parameterised as:

$$\Delta y_{it} = \phi_i y_{it-1} + \beta_i' \mathbf{x}_{it} + \sum_{j=1}^{p-1} \lambda_{ij}^{*} \Delta y_{it-j} + \sum_{j=0}^{q-1} \delta_{ij}^{*}{}' \Delta \mathbf{x}_{it-j} + \mu_i + \varepsilon_{it} \tag{11}$$

where $\phi_i = -\left(1 - \sum_{j=1}^{p} \lambda_{ij}\right)$, $\beta_i = \sum_{j=0}^{q} \delta_{ij}$, $\lambda_{ij}^{*} = -\sum_{m=j+1}^{p} \lambda_{im}$ and $\delta_{ij}^{*} = -\sum_{m=j+1}^{q} \delta_{im}$

In addition we assume that the residuals in (11) are independently distributed across i and t with zero mean, variance greater than zero and finite fourth moments. Secondly, the roots of equation (11) must lie outside the unit circle. The latter assumption ensures that ϕ_i<0, and hence that there exist a long-run relationship between y_{it} and $\mathbf{x}_{it}$ defined by

$$y_{it} = -\left(\beta_i' / \phi_i\right) \mathbf{x}_{it} + \eta_{it} \tag{12}$$

The long-run homogeneous coefficient is equal to $\theta = \theta_i = -\left(\beta_i' / \phi_i\right)$, which is the same across groups. The PMGE uses a maximum likelihood approach to estimate the model and a Newton-Raphson algorithm. The lag length for the model can be determined using, for instance, the Schwarz Bayesian Information Criteria.

For our purposes, the key feature of the PMGE is to make the long-run relationships homogenous while allowing for the heterogeneous dynamics and error variances. We test for long-run homogeneity using, first, a joint Hausman test (see Pesaran, Smith and Im, 1996, for details), and second a Likelihood Ratio approach. The Hausman test is based on the null of equivalence between the PMG and MG estimation. If we reject the null we reject homogeneity of our cross sections' long run coefficients, while significant statistical difference between our two

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important for long run UK investment, it is not a sufficient statistic.

estimators would be indicative of panel mis-specification. The Likelihood Ratio test for long run parameter heterogeneity is more conventional in this setting and has homogeneity as the null hypothesis (see Hsiao, 2003). The Likelihood Ratio statistic always rejects homogeneity in the Pesaran et al. (1999) panel study of aggregate consumption and, as such, can be considered a much more stringent test for poolability than the Hausman test (which typically accepts poolability in the Pesaran et al. study). In Pesaran et al. (ibid), it is suggested that the low power of the Hausman test may be due to the broad standard errors associated with the Mean Group Estimator. Hence evidence from a Hausman test that Pooled Mean Group is not significantly different from Mean Group estimation may not be a reflection of PMG being consistent but merely that MG is inefficient. Given these arguments, we focus largely on the Likelihood Ratio test in the results section below.

Another reason for utilising the PMGE in our empirical work is that the estimated coefficients in the model are not dependent upon whether the variables are $I(1)$ or $I(0)$. Pesaran and Shin (1998) present Monte Carlo evidence that *ARDL* approach based on the delta method can be reliably used in small samples to estimate and test hypotheses on the long run coefficients in cases whether there is a mixture of $I(1)$ and $I(0)$ regressors. We also calculated the Mean Group (MGE) estimator, which is an average of the individual country coefficients. This provides consistent estimates of the mean of the long-run coefficients although they are inefficient if slope homogeneity holds. Under long-run homogeneity, PMG estimates are consistent and efficient.

4. Data

In terms of macroeconomic data needed for the investment function, we use quarterly time series for the G7 countries, namely US, Canada, Japan, UK, Germany, France and Italy. We use the OECD Business Sector Database to obtain data for real business investment (IB), real business sector output (YB) and the real business sector capital stock (KB). Private sector aggregates often include housing investment and the housing stock, which has a different cyclical pattern to business investment. Problems of lack of congruence with investment would arise for alternatives to output such as sales growth. Business sector data also overcomes the problems of transfer from public ownership by including business sector capital, investment and output irrespective of sector of ownership.

Meanwhile, we use the non-financial corporate sector capital stock for Tobin's Q (Q), consistent with the equity stock, which is obtained from sectoral financial accounts published by the various national statistical agencies (for a discussion of these data see Byrne and Davis, 2003b). Cost of capital data are from the NiGEM macromodel database. The cost of capital is calculated as the tax adjusted purchase price of a unit of capital, multiplied by the real post-tax financial cost of capital plus the depreciation rate.

For generating uncertainty proxies, we utilise monthly CPI data, long term interest rate data, nominal and real trade weighted effective exchange rate[8] data, industrial production and the stock market index for the G7 countries over 1968-2001. These are obtained from Primark Datastream. In our investment functions we use the conditional variance of the monthly difference of long rates (DLR) and the log-difference of the nominal effective exchange rate (DER), equity prices (DEQ), industrial production (DIP), consumer price[9] (DP) and the real effective exchange rate (DRER) estimated using GARCH as set out in Section 3.2. In the interests of conciseness, we do not provide details of our GARCH estimates (full details of our conditional variance estimation results are available in Byrne and Davis, 2002). It suffices to note here that significant GARCH effects were present in each case and that the GARCH process in the conditional-variance equation was covariance stationary with $\alpha_1+\beta_1<1$. We note, following Engle (1983) that GARCH generates a model-dependent outcome, although the approach adopted, of differencing the conditional-mean equation sufficiently to avoid autocorrelation, is fairly standard.

[8] We consider the effective rate to be more appropriate than bilateral rates such as those with the US dollar given it distributes exchange rate changes and related volatility appropriately across the export and import markets of the country concerned.
[9] We note that there are arguments for using volatility of the wholesale price index rather than the CPI. The choice was based on the wider economic significance of the CPI and status as a target of monetary policy.

In evaluating the data prior to estimation, in particular to preclude a stationary regressand, we use relatively powerful unit root tests using local GLS detrending and adopt the testing strategy developed in Ng and Perron (2001). Further details and a summary of the test results are given in Table 1.[10] Logs of business investment and business output are $I(1)$, as are most of the times series in levels used in traditional specifications for investment. So too is Tobin's Q, consistent with Cuthbertson and Gasparro (1995). The conditional volatility measures are also typically $I(1)$, although there is consistent evidence that equity price and real exchange rate volatility measures are $I(0)$. As noted, Pesaran and Shin (1998) emphasise that the *ARDL* approach is robust to the inclusion of $I(1)$ and $I(0)$ regressors. Our results from the unit root test suggest that we do not start our analysis with evidence of an unbalanced regression. In this regard, further evidence is provided below of mean reversion to our long run relationships.

5. Results

5.1 Estimation of Investment Functions without Uncertainty

Following the discussion above, in this section we develop a baseline investment function which can be extended for testing the long run relationship between uncertainty and investment using GARCH to derive conditional volatility. We assess an accelerator based investment function (testing for additional cost of capital and Tobin's Q effects) using the Pooled Mean Group Estimator (PMGE) for dynamic heterogeneous panels as well as the mean group estimator (MGE) based on averaging of individual-country results. In addition, we have heterogeneously estimated dynamics, specified by information criteria. Following the approach of Cuthbertson and Gasparro (1995) and Carruth et al. (2000a) to modelling long-run investment, the basic equation is as follows:

$$\Delta \ln(IB)_{it} = \phi_i \left(\ln(IB)_{i,t-1} - \theta_{0i} - \theta_1 \ln(YB)_{it}\right) + \sum_{j=1}^{p} \delta_{ji} \Delta \ln(IB)_{i,t-j} + \sum_{j=0}^{q} \varphi_{ji} \Delta \ln(YB)_{i,t-j} + \varepsilon_{it} \qquad (13)$$

[10] Full details are available in Byrne and Davis (2002).

where in variants we add to the long and short run the additional variables Tobin's Q, the user cost and the long term interest rate. Table 2 focuses solely on the long run components of the estimates. It shows that the long-run coefficient on output is statistically significant, irrespective of which other variables are included in the specification. Also, the error correction term is always significant and negative, which is consistent with a non-spurious relationship, although the implied speed of adjustment is slow, as is typical of estimated investment functions. However, the neoclassical opportunity cost measures of investment, namely the user cost and long term interest rates, are often the wrong sign and are always insignificant. Tobin's Q is significant and positive in sign using the PMGE. Whereas it can be argued that omission of the long rate is surprising it is consistent with many other empirical studies such as Chirinko (1993)[11]. The implication is that the impact of monetary policy takes place via output and also (when included) Tobin's Q. We also acknowledge that the panel specification is fairly simple compared with what is feasible for a single country equation with individual sources available nationally. However, we do note that in terms of dynamics the PMG approach allows for marked cross country diversity in responses (not shown in detail).

It is emphasised in the dynamic panel literature developed in Pesaran and Smith (1995), Lee et al. (1997) and Pesaran et al. (1999) that it is important to consider whether there is slope heterogeneity. This potential characteristic of our cross section can affect the usefulness of our results, in particular, it may bias our pooled estimated coefficients. There is a degree of dispersion of country slopes in our results: The Likelihood Ratio test rejects homogeneity at the 5% significance level when we include output and Tobin's Q in our specification.[12] Given that the most simple specification accepts both tests for poolability, $\chi^2_{LR}\{6\} = 8.45$ [0.21], and slope

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[11] Also Darby et al (1999) only find a cost of capital effect for France among the G-5, while Cuthbertson and Gasparro (1995) note that "time series studies have not yet succeeded in yielding robust tax effects via the cost of capital" (ibid, p938).

[12] The Hausman test statistic suggests poolability when we incorporate only Business Output and Tobin's Q in our long run specification with a test statistic of 0.20 (p-value=0.90). As pointed out by Pesaran et al. (1999) it is often difficult to differentiate between panel specifications on the basis of this test unlike the more stringent Likelihood Ratio test. Indeed the Mean Group coefficient on Tobin's Q is always insignificant. We hence employ Tobin's Q only as a variant to check robustness. The instability of the estimated coefficient on Tobin's Q when output is excluded from the specification, and low likelihood, may well be due to different trending components in investment and Q.

coefficients are significant for both estimators we initially concentrate on the long run equilibrium relationship with output only in our panel study. A sensitivity analysis reintroducing Tobin's Q is noted in Section 5.3 below allowing us to assess whether inclusion of output and uncertainty only leads to significant omitted variables bias.

We cannot accept the hypothesis that the coefficient on output is equal to one in our investment function, whether or not we include the long rate or Q, since the estimated output coefficient reported in the second top row of Table 2 is more than two standard errors away from 1.00. Although Carruth et al. (2000a) and Cuthbertson and Gasparro (1995) both find evidence that the null of output homogeneity is accepted, they also report evidence where the estimated elasticity on output is greater than one. In particular, Cuthbertson and Gasparro's preferred specification has an estimated coefficient greater than one. The fact that we have estimated coefficients in excess of one can be viewed as due to our wider sample and hence more efficient estimated statistics. Our results are consistent with Jones (1995) who report evidence of increasing investment output ratios for the industrialised countries in the post war period and Davis and Madsen (2001) who note a sharp rise in the capital output ratio in the major industrial countries. It may also be linked to an increase in the depreciation rate (where the basic model assumes a constant rate) and increased capital mobility which has made fixed investment more sensitive.

5.2 Impact of Uncertainty on Investment

We turn now to estimation of uncertainty effects on investment. Developing from equation (13), Table 3 presents the estimated long run coefficients and short run error correction term from equation (14).

$$\begin{aligned}\Delta \ln(IB)_{it} &= \phi_i \left(\ln(IB)_{i,t-1} - \theta_{0i} - \theta_1 \ln(YB)_{it} - \theta_2 CV(.)_{it}\right) + \sum_{j=1}^{p} \delta_{ji} \Delta \ln(IB)_{i,t-j} \\ &+ \sum_{j=0}^{q} \varphi_{ji} \Delta \ln(YB)_{i,t-j} + \sum_{j=0}^{r} \gamma_{ji} \Delta CV(.)_{i,t-j} + \varepsilon_{it}\end{aligned} \qquad (14)$$

The long run elasticities on output are always significant and the estimated coefficients are again slightly larger than one in magnitude. Also, the error correction terms are significant, suggesting mean reversion to a long-run relationship. In terms of the measures of volatility, we find for the entire sample period that only the measure of nominal and real exchange rate uncertainty are significant in influencing long-run business investment across the G7 with a PMG estimated elasticity of -8.02 and -0.09 respectively (note that the latter is scaled by 100 to aid convergence of the volatility estimates, so the effects are actually comparable in magnitude). Of the other measures shown in Table 3, namely the conditional variance of equity prices, CV(DEQ), industrial production, CV(DIP), and of inflation, CV(DP), there is often a negative effect from uncertainty of these variables, although we do not find evidence that this is statistically significant across the G7.

The probability values associated with the Hausman test always accepts the null hypothesis of equivalence of PMG and MG and hence implies that there is parameter homogeneity across the G7 as a whole. This is also true for equity prices, industrial production and inflation for the Likelihood Ratio tests. However, we cannot accept parameter homogeneity at 95% for this test for long rate, nominal and real exchange rate uncertainty, although poolability is close to acceptance for the long rate and the real exchange rate. Given the greater credence we attach to the Likelihood Ratio statistic, we pursue the issue of poolability of the exchange rate results by splitting our sample. One possible poolable combination for the nominal and real exchange rate, according to the Joint χ^2_{LR} statistic, can be obtained by combining Germany, France, UK and Italy (Tables 4A and 4B). In this instance the uncertainty coefficient increases as does the significance, to -11.81 (t-statistic=3.31) for the nominal rate and -0.13 (3.23) for the real rate. We also find a greater speed of mean reversion to the equilibrium relationship.

5.3 Sensitivity Analysis

To assess the robustness of our results, we considered it important to examine the stability of our estimates across time. We do so by splitting our sample period in the early 1980s, dividing the data roughly in half, and also estimating the uncertainty coefficient recursively. By these means, we can examine whether the importance of exchange rate volatility has increased or diminished over time, or indeed whether other types of volatility have important effects which are obscured in estimation results for the entire sample.

The results from splitting the time series span into two sub-samples (Tables 5 and 6) show that in the earlier sample period, 1973Q1 to 1983Q4, exchange rate volatility only has a significant effect on investment at the 10% significance level; the estimated coefficient is -5.16 (t-statistic = -1.80). However, for the later period the effect from the nominal effective exchange rate increases in both magnitude and significance (the coefficient becomes -41.59, t-statistic = 2.42). There are similar increases in the real rate coefficient. We note also that the output coefficients are closer to one in the later sample, in the case of exchange rates and long rates. These results on the impact of exchange rate volatility are confirmed by the recursively estimated coefficients (and standard error bands) in Figure 1 and 2.[13] From the figures we see exchange rate volatility becoming more important when we incorporate more recent data into our sample period. For some of the earlier periods there does not appear to be a strongly negative coefficient. But as we move into the 1990s the coefficient decreases further below zero (approximately by a factor of two).

In the latter period, hedging was more common. This may be balanced by greater reliance on external as opposed to internal finance for investment in the later period, (although note that the Modigliani-Miller theorem implies that this should be "irrelevant") and possibly greater capital mobility. Another explanation may be that firms are less sensitive to exchange rates when they are in a situation of imperfect competition. In the second half of the sample, financial liberalisation, anti trust policy, privatisation, removal of trade barriers and other forms of market opening have been much more marked. There has also been an increase in the range of goods and

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[13] We believe our approach to recursive estimation of PMGE is highly appropriate for testing the stability of coefficients in a panel data study.

services which are traded. The resulting increased contestability may underlie the shifting coefficient and growing impact of uncertainty.

There is evidence of cross sectional homogeneity of the long run coefficients for the later period using both the tests when we incorporate nominal exchange rate volatility into our specification (Table 5B, columns 2 and 3). The industrialised countries' macroeconomic structures with respect to investment, openness and the exchange rate volatility are, this result suggests, becoming increasingly similar. This may again be linked to increased product market liberalisation, capital mobility, increased openness and market efficiency.

The G7 results for the volatility of Industrial Production gives us some indication in the earlier period that there is a significant positive effect on investment in the long run. However, we discount this result here since the estimated coefficient is only marginally significant, the error correction term is insignificant at the 5% level (suggesting the absence of a long run relationship between investment and uncertainty) with no evidence of poolability from either the LR or Hausman statistic.

With regards to the long-run interest rate, the estimated coefficient in the later period is significant at the 5% level and negative (-0.23). Although we have a reasonable specification (e.g. a significant error correction term) panel poolability is rejected using the LR test statistic, and only accepted with the less stringent Hausman test. Consequently we again consider whether it is possible to split the cross section sample in Table 6. Germany and Italy appear to behave similarly with regard to long-run interest rate volatility. This is shown by the likelihood ratio statistic, which is insignificant by a large margin when we combine these two countries. Our results are somewhat surprising since Italy is typically considered as an economic "outsider" with regard to EMU, see for example the evidence from Darby et al. (1999). In this instance it is clearly exhibiting similar behaviour to the largest European economy. We do not find such clear evidence for combined significance and poolability for France or the UK with regards the volatility of long interest rates. But if anything the evidence sides with the UK exhibiting relatively (i.e. compared to France) similar behaviour to Italy and Germany. The LR statistic is borderline significant at the 5% level and uncertainty is having a negative effect, with a coefficient of -0.45.

We seek to calibrate the impact of uncertainty on investment in the context of the successful results highlighted above. These are shown in Table 7. It can be seen that a 10% rise in the level of exchange rate or long rate volatility relative to the average leads to a fall in investment of 1-1.5% except in the case of the later period exchange rate coefficient (5%) and the long rate for the G7 in the later sample (0.7%). Using the standard deviation of volatility as a benchmark, a 1 standard deviation rise in conditional volatility leads to a 2-4% fall in investment for the full sample G7 exchange rate and both the long rate estimates. In the case of the EU exchange rate the effect is 7%, and 20% for the G7 exchange rate in the later sample.

Two further experiments were undertaken to test the robustness of the main results. First, we introduced Tobin's Q to the same equations, following Cuthbertson and Gasparro (1995) and also to test the empirical finding of Leahy and Whited (1996) that uncertainty proxies may be irrelevant in the presence of Q – or conversely that exclusion of Q led to omitted variables bias. Broadly speaking, the results (Table 8) do not controvert our main findings. Q is significant at around 0.16 in all of the PMG estimates. When including Tobin's Q, the nominal and real effective exchange rate remain significant in the PMG estimates. We can only accept poolability with the Hausman test, however. Second, we removed time means from the variables in the panel as a means of accounting for residual correlation across cross-sections[14] but this again does little to the results.[15] Third, in Byrne and Davis (2002) we reported PMG results for the Kenen and Rodrick and rolling standard deviation measures of uncertainty. Results are statistically weaker and economically less plausible than for GARCH,[16] thus lending support to the theoretical arguments we have presented in favour of the superiority of GARCH as a measure of uncertainty.

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[14] Technically, this deals with common unobserved global factors which have the same effect on individual countries, as may have occurred in the 1979 oil crisis for example.

[15] Results are available upon request.

[16] The PMG estimates using these moving-average measures of exchange rate volatility did not provide results in favour of a negative effect from exchange rate volatility on investment. Of the other variables considered, there is some indication of a negative effect from inflation. The implications of unconditional volatility for monetary policy reactions may be a reason why it is moving average and not GARCH measures of inflation volatility that come to the

6. Conclusions

This paper contributes to the empirical literature on investment and uncertainty by assessing a full range of sources of uncertainty and implementing evidence from pooled mean group estimation. We can thus test explicitly for differences across countries and benefit from both cross section and time series evidence when testing the relationship between investment and uncertainty. Our panel approach has the additional benefit that it is based on the *ARDL* approach which is robust to the incorporation of $I(1)$ and $I(0)$ regressors. We also suggest that utilising a GARCH methodology is an improvement on moving average measures of volatility, as the latter may only measure sample variability rather than uncertainty. The empirical evidence presented in this paper shows unequivocally that exchange rate uncertainty is harmful to investment, both for the G7 and for all subsamples. There is evidence of a growing exchange rate effect over the sample. A long term interest rate effect also emerges for major EU countries other than France over the 1984-96 period. For most estimates, a one standard deviation rise in conditional volatility of effective exchange rates or long rates leads to a 2-4% fall in investment although some samples give much greater declines. Results for uncertainty of inflation, equity prices and industrial production do not, in contrast, suggest that these variables have a major and consistently negative effect on investment across the G7.

As regards the implications for EMU, the panel results suggest it is of benefit for all the large EU countries, including the UK, to reduce effective exchange rate and long rate volatility. Since it is likely that EMU will reduce trade-weighted nominal exchange rate volatility (where even for the UK, over 50% of trade is with the euro area), EMU is indicated to favour investment. This will be the case as long as EMU does not boost real exchange rate volatility (owing to differential inflation rates), or lead to much greater volatility in the remaining floating bilateral rates (basically the yen and dollar) that form the trade weighted baskets of the UK and other large

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fore. Finally, short, and long interest rates and the equity price series provided little evidence of any effect. In none of the estimates was poolability accepted with the likelihood ratio test.

EU countries. Neither of these seems very likely. Equally, for some countries EMU may also reduce long rate volatility (given, for example, a deeper and more liquid bond market, lower fiscal deficits and less volatile short rates). This would compound the beneficial effect.

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Table 1: Unit Root Tests

	US	*CN*	*FR*	*GE*	*IT*	*JP*	*UK*
ln(IB)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)
ln(IB)*	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)
ln(YB)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)
ln(YB)*	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)
Tobin's Q	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)
Tobin's Q*	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)
User Cost	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)
User Cost*	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)
Long Interest Rate	*I*(1)	*I*(1)	*I*(1)	*I*(0)	*I*(1)	*I*(1)	*I*(1)
Long Interest Rate*	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)
CV(DER)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(0)
CV(DER)*	*I*(1)	*I*(0)	*I*(0)	*I*(1)	*I*(1)	*I*(1)	*I*(0)
CV(DP)	*I*(1)	*I*(1)	*I*(1)	*I*(0)	*I*(1)	*I*(1)	*I*(1)
CV(DP)*	*I*(0)	*I*(0)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)
CV(DEQ)	*I*(0)	*I*(1)	*I*(0)	*I*(0)	*I*(0)	*I*(0)	*I*(0)
CV(DEQ)*	*I*(0)	*I*(1)	*I*(1)	*I*(1)	*I*(0)	*I*(0)	*I*(0)
CV(DIP)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(0)
CV(DIP)*	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(1)
CV(DRER)	*I*(0)	*I*(0)	*I*(1)	*I*(0)	*I*(1)	*I*(1)	*I*(0)
CV(DRER)*	*I*(1)	*I*(0)	*I*(1)	*I*(1)	*I*(1)	*I*(1)	*I*(0)
CV(DLR)	*I*(0)	*I*(0)	*I*(1)	*I*(0)	*I*(1)	*I*(1)	*I*(1)
CV(DLR)*	*I*(1)	*I*(1)	*I*(1)	*I*(0)	*I*(0)	*I*(0)	*I*(1)

Notes: Sample period 1973Q1 to 1996Q4. Asterisk (*) indicates trend in unit root specification. CV(.) is the conditional variance from GARCH estimation. Table summarises evidence from Byrne and Davis (2002) including: *MZa* and *MZt* Modified Phillips-Perron tests; a Modified Sargan-Bhargava test; Elliott, Rothemberg and Stock feasible point optimal test (*ERS Pt*); a modified point optimal test; and *DF-GLS* the Augmented Dickey Fuller test.

Table 2: Basic Investment Function

	ln(YB)	Tobin's Q	User Cost	Long Interest Rate	*Error Correction*	*MLL*	$\chi^2_{LR}\{\cdot\}$	$\chi^2_{H}\{\cdot\}$
PMGE	**1.367** **(t=24.610)**				**-0.082** **(-6.461)**	1648.783 <1653.010>	8.45 [*p*=0.21]	0.20 [0.65]
MGE	**1.393** **(18.322)**				**-0.092** **(-5.818)**			
PMGE	**1.247** **(29.271)**	**0.166** **(3.233)**			**-0.091** **(-6.908)**	1653.317 <1666.087>	**25.54** **[0.01]**	0.20 [0.90]
MGE	**1.250** **(10.998)**	0.388 (0.743)			**-0.103** **(-6.043)**			
PMGE	**1.247** **(26.037)**	**0.169** **(3.243)**	-0.005 (0.013)		**-0.089** **(-6.550)**	1650.481 <1678.085>	**55.21** **[0.00]**	3.34 [0.34]
MGE	**1.482** **(6.757)**	0.292 (0.375)	0.381 (0.319)		**-0.117** **(-7.371)**			
PMGE	**1.346** **(24.047)**		-0.523 (-0.931)		**-0.083** **(-6.543)**	1644.076 <1651.366>	14.58 [0.28]	1.47 [0.48]
MGE	**1.443** **(15.648)**		0.120 (0.191)		**-0.103** **(-7.613)**			
PMGE	**1.258** **(26.526)**	**0.171** **(3.286)**		0.002 (-0.468)	**-0.092** **(-7.018)**	1653.400 <1673.014>	**39.23** **[0.00]**	na
MGE	**1.218** **(11.578)**	0.380 (0.968)		0.006 (-0.994)	**-0.120** **(-7.158)**			
PMGE	**1.359** **(24.150)**			-0.002 (-0.385)	**-0.082** **(-6.608)**	1651.637 <1659.466>	15.66 [0.21]	na
MGE	**1.359** **(13.857)**			-0.002 (-0.253)	**-0.102** **(5.690)**			
PMGE		**8.948** **(5.554)**			-0.010 (-1.199)	1484.742 <1491.177>	**12.87** **[0.05]**	0.13 [0.71]
MGE		7.446 (1.688)			**-0.033** **(-3.023)**			

Notes: The dependent variable is Business Investment and the table shows the long-run coefficients from variants of equation (13). Business output is ln(YB). Estimation is by Pooled Mean Group (PMGE) and Mean Group (MGE). Sample period 1973Q1 to 1996Q4. The *ARDL* lag structure is determined by the Schwarz Bayesian Information Criteria. $\chi^2_{LR}\{.\}$ denotes the Likelihood Ratio Statistic, large values reject poolability of our cross sections. $\chi^2_{H}\{.\}$ is the Hausman test for poolability which is a test for the equivalence of PMGE and MGE. If the null hypothesis is accepted (i.e. *p*-value greater than 0.05) we can accept homogeneity of cross sectional long run coefficients. As discussed in Pesaran et al. (1996) there is no guarantee that the difference between the variance of the mean group and pooled estimator used to calculate $\chi^2_{H}\{.\}$ is positive definite (such results are denoted here by na). t-statistics based on asymptotic standard errors are in parentheses (·). *p*-values are in square brackets [·]. *MLL* is the maximised log likelihood, unrestricted *MLL* is in brackets <·>.

Table 3: Panel Estimation of Investment and Uncertainty: G7 Countries

	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE
ln(YB)	**1.346 (24.944)**	**1.439 (11.637)**	**1.377 (26.591)**	**1.466 (13.144)**	**1.363 (24.610)**	**1.370 (15.647)**	**1.348 (27.205)**	**1.413 (14.931)**	**1.348 (30.071)**	**1.390 (18.593)**	**1.371 (24.720)**	**1.439 (14.851)**
CV(DER)	**-8.018 (-2.887)**	**-25.198 (-2.097)**										
CV(DEQ)			0.374 (0.585)	-0.758 (-0.362)								
CV(DP)					-6.863 (-0.787)	-22.596 (-1.069)						
CV(DIP)							-0.067 (-1.189)	11.629 (0.817)				
CV(DLR)									0.020 (0.302)	0.076 (0.680)		
CV(DRER)											**-0.094 (-2.780)**	-0.256 (-1.547)
Error Correction	**-0.077 (-5.270)**	**-0.083 (-4.431)**	**-0.084 (-6.403)**	**-0.095 (-4.926)**	**-0.079 (-6.244)**	**-0.093 (-6.132)**	**-0.083 (-6.241)**	**-0.095 (-5.544)**	**-0.086 (-6.510)**	**-0.112 (-5.553)**	**-0.078 (-5.661)**	**-0.081 (-4.429)**
MLL	1652.252 <1667.613>		1649.147 <1655.401>		1645.014 <1654.103>		1649.533 <1654.573>		1646.737 <1657.649>		1651.887 <1662.906>	
$\chi^2_{LR}\{.\}$	**30.72 {12} [*p*=0.00]**		12.51 {12} [0.41]		18.18 {12} [0.11]		10.08 {12} [0.61]		**21.83 {12} [0.04]**		**22.03 {12} [0.04]**	
$\chi^2_H\{.\}$	3.44 {12} [0.18]		1.39 {12} [0.50]		1.47 {12} [0.48]		1.64 {12} [0.44]		0.50 {12} [0.78]		2.18 {12} [0.34]	

Notes: The dependent variable is Business Investment and the results are the long-run coefficients from equation (14). Estimation is by Pooled Mean Group (PMGE) and Mean Group (MGE). Sample period 1973Q1 to 1996Q4. *ARDL* lag structure determined by the Schwarz Bayesian Information $\chi^2_{LR}\{.\}$ denotes the Likelihood Ratio Statistic, large values reject poolability of our cross sections. $\chi^2_H\{.\}$ is the Hausman test for poolability and tests for the equivalence of PMGE and MGE. If the null hypothesis is accepted (i.e. *p*-value greater than 0.05) we can accept homogeneity of cross sectional coefficients. CV(.) is the conditional variance from GARCH estimation. DER is the first difference of the log of the nominal effective exchange rate. DEQ the first difference of the log of the stock exchange index. DP is the first difference of the log of the consumer price index. DIP is the first difference of the log of industrial production. DLR is the first difference of the long interest rate. DRER is the first difference of the log of the real effective exchange rate. Underlying GARCH (1,1) estimates are given in Byrne and Davis (2002). t-statistics based on asymptotic standard errors are in parentheses (·). *p*-values are in square brackets [·]. *MLL* is the maximised log likelihood, unrestricted *MLL* is in brackets <·>.

Table 4A: PMGE Investment and Nominal Exchange Rate Sub Samples

	PMGE	MGE	PMGE	MGE	Individual Coefficients $\chi^2_{LR}\{.\}$
ln(YB)	**1.346 (t=24.944)**	**1.439 (11.637)**	**1.233 (21.371)**	**1.202 (63.534)**	0.221 {3} [*p*=0.97]
CV(DER) G7	**-8.018 (-2.887)**	**-25.198 (-2.097)**			
CV(DER) EU4			**-11.808 (-3.312)**	**-12.670 (-2.852)**	3.826 {3} [0.28]
Error Correction	**-0.077 (-5.270)**	**-0.083 (-4.431)**	**-0.094 (-3.855)**	**-0.097 (-4.578)**	
Joint Coefficients $\chi^2_{LR}\{.\}$	**30.72 {12} [0.00]**		4.19 {6} [0.65]		
$\chi^2_H\{.\}$	3.44 {12} [0.18]		na		

Notes: EU4 consists of France, Germany, Italy and the UK. See also Tables 2 and 3. t-statistics in parentheses. *p*-values in square brackets [·]. Sample period 1973Q1 to 1996Q4. $\chi^2_{LR}\{.\}$ denotes the Likelihood Ratio Statistic. $\chi^2_H\{.\}$ is the Hausman test.

Table 4B: PMGE Investment and Real Exchange Rate Sub Samples

	PMGE	**MGE**	**PMGE**	**MGE**	Individual Coefficients $\chi^2_{LR}\{.\}$
ln(YB)	**1.371 (24.720)**	**1.439 (14.851)**	**1.265 (21.711)**	**1.253 (35.919)**	0.868 {3} [*p*=0.83]
CV(DRER) G7	**-0.094 (-2.780)**	-0.256 (-1.547)			
CV(DRER) EU4			**-0.134 (-3.232)**	**-0.136 (-3.522)**	2.132 {3} [0.55]
Error Correction	**-0.078 (-5.661)**	**-0.081 (-4.429)**	n.a.‡	n.a.‡	
Joint Coefficients $\chi^2_{LR}\{.\}$	**30.41 {12} [0.00]**		3.343 {6} [0.76]		
$\chi^2_H\{.\}$	2.18 [0.34]		na		

Notes: EU4 consists of France, Germany, Italy and the UK. See also Tables 2 and 3. ‡ This is due to a problem with an Italian dynamic lag length greater than one. Reducing the maximum lag length to one, reduced the pooled coefficient to -0.142 without changing the individual country results for the other countries and producing a significant error correction term for PMGE. Sample period 1973Q1 to 1996Q4.

Table 5A: Panel Estimation of Investment and Uncertainty: G7 Countries Time Split 1: 1973Q1 to 1983Q4.

	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE
ln(YB)	**1.412 (5.164)**	**1.121 (4.256)**	**1.446 (10.837)**	**1.140 (3.378)**	**1.444 (12.217)**	**1.473 (6.381)**	**1.574 (11.845)**	**1.219 (6.541)**	**1.436 (10.787)**	**1.324 (4.874)**	**1.421 (10.424)**	**1.252 (4.329)**
CV(DER)	-5.164 (-1.803)	-13.144 (-1.325)										
CV(DEQ)			-0.317 (-0.412)	4.300 (0.890)								
CV(DP)					-0.990 (-0.198)	17.526 (1.318)						
CV(DIP)							**6.437 (1.994)**	35.891 (1.025)				
CV(DLR)									0.108 (0.982)	-0.134 (-0.755)		
CV(DRER)											-0.041 (-1.480)	-0.044 (-0.632)
Error Correction	**-0.115 (-2.855)**	**-0.083 (-4.431)**	**-0.120 (-3.034)**	**-0.197 (-2.285)**	**-0.079 (-6.244)**	**-0.093 (-6.132)**	-0.072 (-1.680)	**-0.212 (-2.276)**	**-0.123 (-3.053)**	**-0.213 (-2.589)**	**-0.119 (-2.939)**	**-0.210 (-2.632)**
$\chi^2_{LR}\{.\}$	**34.65 {12} [0.00]**		**29.01 {12} [0.00]**		**22.88 {12} [0.03]**		**37.32 {12} [0.00]**		**23.22 {12} [0.03]**		**30.224 {12} [0.00]**	
$\chi^2_{H}\{.\}$	**6.88 {12} [0.03]**		1.21 {12} [0.55]		2.27 {12} [0.32]		**11.77 {12} [0.00]**		3.24 {12} [0.20]		0.99 {12} [0.61]	

Notes: See Tables 2 and 3

Table 5B: Panel Estimation of Investment and Uncertainty: G7 Countries Time Split 2: 1984Q1 to 1996Q4.

	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE
ln(YB)	**1.150 (9.811)**	**1.562 (2.841)**	**0.765 (3.953)**	**1.098 (1.979)**	**2.227 (7.062)**	**2.049 (2.398)**	0.611 (0.248)	2.382 (1.892)	**1.158 (12.919)**	**2.897 (2.028)**	**1.131 (8.578)**	**2.222 (1.739)**
CV(DER)	**-41.593 (-2.422)**	-49.053 (-1.904)										
CV(DEQ)			0.673 (0.499)	-3.271 (-1.195)								
CV(DP)					19.001 (1.032)	41.121 (0.285)						
CV(DIP)							-9.056 (-0.958)	-24.541 (-0.436)				
CV(DLR)									**-0.227 (-2.268)**	0.359 (0.292)		
CV(DRER)											**-0.452 (-2.361)**	**-0.966 (-1.330)**
Error Correction	**-0.084 (-6.403)**	**-0.095 (-4.926)**	-0.043 (-1.807)	**-0.098 (-3.904)**	-0.039 (-1.740)	**-0.091 (-3.454)**	-0.028 (-1.198)	**-0.093 (-3.775)**	**-0.082 (-4.510)**	**-0.091 (-3.269)**	**-0.036 (-2.535)**	**-0.078 (-3.174)**
$\chi^2_{LR}\{.\}$	18.18 {12} [p = 0.11]		**34.69 {12} [0.00]**		**42.73 {12} [0.00]**		**38.20 {12} [0.00]**		**45.97{12} [0.00]**		**33.214 {12} [0.00]**	
$\chi^2_{H}\{.\}$	1.39 {12} [0.50]		2.78 {12} [0.25]		0.56 {12} [0.76]		**7.01 {12} [0.03]**		2.79 {12} [0.25]		0.79 {12} [0.67]	

Figure 1: The Long-Run Recursive PMGE Coefficient for Nominal Exchange Rate Uncertainty

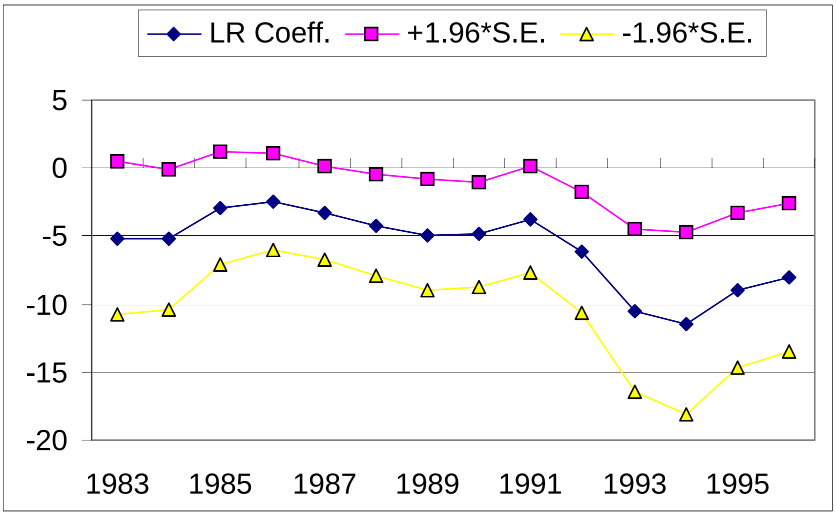

Figure 2: The Long-Run Recursive PMGE Coefficient for Real Exchange Rate Uncertainty

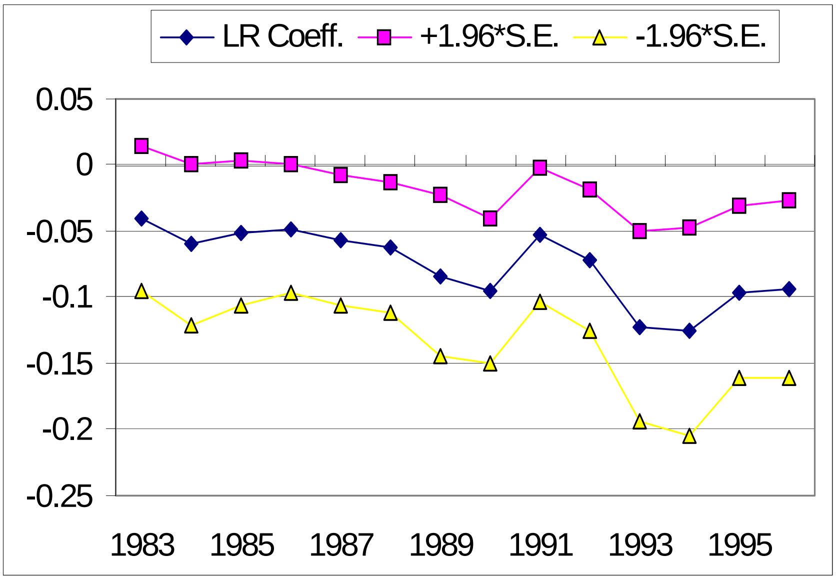

Table 6: Panel estimates for Long Interest Rates: European Countries later Panel

	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE
ln(YB)	**1.158 (12.919)**	**2.897 (2.028)**	**0.876 (5.049)**	1.495 (1.820)	**1.105 (9.487)**	**1.288 (5.286)**	**0.879 (5.033)**	0.767 (1.424)	**1.106 (9.584)**	**2.085 (2.576)**
CV(DLR) G7	**-0.227 (-2.268)**	0.359 (0.292)								
CV(DLR) FR, GE, IT & UK			-0.215 (-1.114)	1.630 (0.969)						
CV(DLR) GE & IT					**-0.473 (-2.026)**	**-0.511 (-4.938)**				
CV(DLR) GE, IT & FR							-0.242 (-1.254)	-0.014 (-0.028)		
CV(DLR) GE, IT & UK									**-0.452 (-2.023)**	1.847 (0.783)
Error Correction	**-0.082 (-4.510)**	**-0.091 (-3.269)**	**-0.068 (-8.340)**	**-0.078 (-4.268)**	**-0.101 (-4.560)**	**-0.105 (-11.409)**	**-0.076 (-11.701)**	**-0.080 (-3.142)**	**-0.077 (-2.709)**	**-0.093 (-7.332)**
$\chi^2_{LR}\{.\}$	**45.97{12} [0.00]**		**22.00 {6} [0.00]**		1.97 {2} [0.37]		**14.73 {4} [0.01]**		**9.51 {4} [0.05]**	
$\chi^2_{H}\{.\}$	2.79 {12} [0.25]		1.25 {6} [0.54]		na		na		na	

Notes: Sample period 1984Q1-1996Q4, see Tables 2 and 3.

Table 7: The economic impact of uncertainty on investment

Sample	*Variable*	*Average level of cv.*	*Coefficient*	*Base level*	*10% rise*	*1 std dev*	*50% rise*
1973-1996	G7 nominal exchange rate	0.013	-8.018	-0.107	-0.011	-0.037	-0.054
1973-1996	EU4 nominal exchange rate	0.012	-11.800	-0.146	-0.015	-0.070	-0.073
1973-1996	G7 real exchange rate	1.41	-0.094	-0.133	-0.013	-0.035	-0.066
1973-1996	EU real exchange rate	1.27	-0.134	-0.171	-0.017	-0.064	-0.085
1984-1996	G7 nominal exchange rate	0.013	-41.600	-0.534	-0.053	-0.202	-0.267
1984-1996	G7 long rate	0.311	-0.227	-0.074	-0.007	-0.021	-0.037
1984-1996	EU3 long rate	0.298	-0.452	-0.144	-0.014	-0.035	-0.072

Notes: base level is equal to the coefficient times the average level of conditional variance (cv) over the sample. Since the investment function is specified in logs, 0.01 is equivalent to a 1% change.

Table 8: Panel Estimation of Investment and Uncertainty with Tobin's Q

	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE	PMGE	MGE
ln(YB)	**1.247 (29.271)**	**1.250 (10.998)**	**1.282 (22.641)**	**1.245 (10.272)**	**1.236 (25.336)**	**1.198 (12.887)**	**1.255 (27.397)**	**1.284 (12.029)**	**1.243 (28.968)**	**1.248 (12.774)**	**1.236 (30.469)**	**1.261 (12.909)**	**1.259 (28.733)**	**1.240 (12.577)**
Q	**0.166 (3.233)**	0.388 (0.743)	**0.210 (2.218)**	0.487 (1.059)	**0.166 (3.031)**	0.360 (0.662)	**0.227 (4.325)**	0.338 (0.842)	**0.164 (3.155)**	0.375 (0.720)	**0.173 (3.665)**	0.335 (0.871)	**0.165 (2.992)**	0.506 (1.024)
CV(DER)			**-7.135 (-2.717)**	**-23.609 (-2.154)**										
CV(DP)					-4.143 (-0.643)	-40.500 (-1.360)								
CV(DEQ)							-0.679 (-1.099)	0.238 (0.086)						
CV(DIP)									-0.047 (-1.203)	13.584 (0.838)				
CV(DLR)											-0.049 (-1.092)	0.134 (1.045)		
CV(DRER)													**-0.076 (-3.096)**	-0.252 (-1.672)
Error Correction	**-0.091 (-6.908)**	**-0.103 (-6.043)**	**-0.079 (-5.542)**	**-0.030 (-2.153)**	**-0.089 (-7.036)**	**-0.100 (-5.822)**	**-0.085 (-7.007)**	**-0.112 (-4.870)**	**-0.091 (-6.953)**	**-0.103 (-5.991)**	**-0.090 (-6.630)**	**-0.117 (-6.097)**	**-0.089 (-6.252)**	**-0.093 (-4.809)**
MLL	1653.32 <1666.09>		1654.2597 <1678.1378>		1653.5399 <1668.2952>		1650.51 <1675.51>		1654.07 <1667.37>		1653.72 <1673.95>		1660.75 <1677.56>	
$\chi^2_{LR}\{.\}$	**25.54 {12} [0.01]**		**47.76 {18} [0.00]**		**29.51 {18} [0.04]**		**50.00 {18} [0.00]**		26.59 {18} [0.09]		**40.46 {18} [0.00]**		**33.62 {18} [0.01]**	
$\chi^2_{H}\{.\}$	0.20{12} [0.90]		**11.15{18} [0.01]**		**5.81**{18} [0.12]		0.16{18} [0.98]		1.01{18} [0.80]		2.51{18} [0.47]		2.24 {18} [0.52]	

Notes: See Tables 2 and 3

Abstract

Empirical work on uncertainty and investment to date is generally single-country or single-indicator. We consider the impact of a range of sources of uncertainty on aggregate business investment across the G7, using Pooled Mean Group Estimation, and GARCH methods to model uncertainty. Significant negative long run effects from effective trade-weighted exchange rate volatility are found for the G7 and in poolable subgroups including all four larger EU countries. Volatility of long rates also influenced investment recently. A one standard deviation rise in conditional volatility generally leads to 2-4% lower investment. The results suggest inter alia that EMU is beneficial to aggregate investment.

Keywords: Investment; Uncertainty; Exchange Rates, Non-Stationary Panel Estimation.
JEL Classification Numbers: E22, F31.