PANEL ESTIMATION OF THE IMPACT OF EXCHANGE RATE UNCERTAINTY ON INVESTMENT IN THE MAJOR INDUSTRIAL COUNTRIES

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Abstract

We estimate the impact of exchange rate uncertainty on investment, using panel estimation featuring a decomposition of exchange rate volatility derived from the components GARCH model of Engle and Lee (1999). For a poolable subsample of EU countries, it is the transitory and not the permanent component of volatility which adversely affects investment, implying high frequency shocks of the type that may be generated by volatile short term capital flows are most deleterious for investment. Results based on EGARCH also suggest that the response of investment to exchange rate uncertainty may depend partly on the sign of the initial shock. (100 words)

Keywords: Investment; Uncertainty; Panel Estimation, Components GARCH.
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1. Introduction

There is growing interest in economic uncertainty and its influence on the level of investment. Some early neoclassical models emphasised that there is a positive impact from uncertainty on investment; see Hartman (1972) and Abel (1983). Recently, following the work of Dixit and Pindyck (1994) there has been a greater emphasis on the deleterious impact of economic and financial volatility on investment. Generally, empirical work tends to imply a negative impact, although zero or even positive results have also been found by some researchers. For example, Goldberg (1993) and Darby et al. (1999) found evidence that exchange rate uncertainty can have significant negative long run effects on investment. Using recent developments in panel econometrics, Byrne and Davis (2002) presented formal statistical evidence of similarities between the larger European countries, with uncertainty having a significant negative effect on investment. Their work highlighted the importance of exchange rate and, to a certain extent, long interest rate volatility. From a UK perspective, this is interesting because differences between European countries will determine the benefits of a single currency, and the reduction in exchange rate uncertainty is one of the primary benefits of Euro Area membership.

There has been some recent work on further decomposing macroeconomic volatility and assessing its impact on the real economy, which emphasise that the source of uncertainty matters. Recent theoretical work by Baum et al. (2001) has highlighted the potential importance of separating permanent from transitory volatility in assessing the real impact of uncertainty. Chadha and Sarno (2002) provide evidence of a differential impact of price uncertainty on investment, depending upon whether the uncertainty is long or short run, with short run volatility being most damaging. The authors use an unobserved-components technique employing Kalman Filtering and maximum likelihood estimation to separate permanent and transitory components of price uncertainty. Chadha and Sarno suggest their results are a useful first attempt at this problem, but would benefit from further corroboration – as is provided here. Developing from these strands of work, we investigate the impact on investment of permanent versus transitory components of exchange rate uncertainty, using the methods of Engle and Lee (1999). These authors decompose the conditional volatility from a GARCH model into a time varying trend and deviations from that trend. As a second issue Baum et al. (2001) also highlight the potential for asymmetries in uncertainty depending on the sign of the initial shock. We consider whether there are non-linearities from exchange rate uncertainty to investment using the exponential GARCH of Nelson (1991).

To motivate our approach, we first provide a brief overview of relevant work on theoretical effects of uncertainty on investment; investment functions; empirical work on uncertainty and investment; measurement of uncertainty; and panel estimation. Against this background, we then proceed to our empirical work, firstly presenting results for component GARCH and exponential GARCH, followed by a direct assessment of uncertainty in investment functions. We employ the Pesaran et al. (1999) Pooled Mean Group approach to panel estimation in investment functions. This panel estimation approach is, we contend, a useful tool for conducting our analysis, given panel methods benefit from the additional information contained in the cross sections and provides us with a framework to test differences across countries. Besides looking at the G7 as a whole, we focus on the behaviour of the UK, France, Italy and Germany given the EMU context. We assess against a baseline of GARCH (1,1) results the evidence for differential impact on investment of temporary and permanent components of exchange rate uncertainty derived using a components GARCH model, as well as asymmetric effects of positive and negative shocks using EGARCH.

2. Literature survey

2.1 Uncertainty and investment

The basic intuition of the effect of uncertainty on investment stems from the option characteristics of an investment project, given the option of delaying the project and its irreversibility once begun, together with the uncertainty over future prices that will determine its profitability. The value of the option arises from the fact that delaying the project may give a more accurate view of market conditions (see Dixit and Pindyck, 1994). 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.

This contrasts with the views of Hartman (1972) and Abel (1983) who 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 strongly on the labour share of firms' costs.

2.2 Investment functions

To investigate such effects empirically at a macro level requires an appropriate specification for investment. The neoclassical model of investment behaviour from Jorgenson (1963) suggests the capital stock is determined by output and the user cost of capital

$$K^* = \frac{\alpha Y}{C_k^{\sigma}} \tag{1}$$

where K^* is the desired capital stock, α is a constant, Y is the level of output, C_k is the user cost of capital and σ is the elasticity of substitution. Substituting investment for the capital stock, we obtain the following long-run relationship

$$\ln(I_t) = \theta_0 + \theta_1 \ln(Y_t) + \theta_2 \ln(C_t) \tag{2}$$

Equation (2) provides the basis for our approach to modelling investment, as developed by Bean (1981) and utilised in work such as Darby et al. (1999). As set out in equation (2), the long run determination of investment is based on a simple accelerator model and presumes costs of adjustment apply to this long run equilibrium. Short run dynamics may be added to form a model in error correction format.

An alternative broad approach to the determination of aggregate investment behaviour (Tobin, 1969), whose insights we also employ in our empirical work, argues that investment should be increasing in the ratio of the equity value of the firm to the replacement cost of the capital stock. This ratio is known as Tobin's Q or *average Q*. Consequently the investment function can be represented as

$$I = \beta Q \tag{3}$$

the parameter β is strictly positive. Further investment should be undertaken and the capital stock increased, if Q is greater than one, and vice versa for values of Q less than one. Abel

(1980) and others have shown that if there are adjustment costs, then investment is dependent on the level of *marginal Q,* the ratio of the future marginal returns on investment to the current marginal costs of investment. Values of marginal Q above one will provide a stimulus to investment.

Unfortunately marginal Q is unobservable; however Hayashi (1982) demonstrated that when the production and adjustment cost functions adhere to certain homogeneity conditions (implying inter alia that there is no market power) then marginal and average Q are equal. So in practice, empirical researchers have included measures of average Q in their investment equations.[1] Often, as in Ashworth and Davis (2001) and the current work, the specification chosen is a hybrid including a term in Q to the basic neoclassical function instead of the cost of capital.

2.3 Empirical work on investment and uncertainty

An extensive survey of the literature on investment and uncertainty is provided in Carruth et al. (2000) and they suggest there is a reasonable consensus in the empirical literature that the effect of uncertainty on aggregate investment is negative. However, a number of issues arise in the literature. One is *choosing the variable to measure volatility*. For example, it is argued in Carruth et al. (2000) 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. Meanwhile, macroeconomic proxies are generally partial – the exchange rate is most relevant to an exporting company for example, but less so to a producer of non-traded goods or services. In this context, Byrne and Davis (2002) assessed a range of uncertainty measures in the G-7, including measures based on volatility of exchange rates, long term interest rates, inflation, share prices and industrial production. Only uncertainty measures based on exchange rates and, to a lesser extent, long rates were found to be significant.

There is then the issue of *how to measure volatility*. Papers that have used ARCH or GARCH measures of macroeconomic variables when modelling investment include Huizinga (1993), Episcopes (1995) and Price (1995). Huizinga (1993), for example, considered volatility of US inflation, real wages and real profits and generally found a

[1] See for example Cuthbertson and Gasparro (1995) for UK evidence and Sensenbrenner (1991) for evidence from 6 OECD countries.

negative effect on investment. See also Callen, Hall and Henry (1990) for an application of GARCH for measuring effects of output volatility on inventory investment. As regards work using alternative measures, Driver and Moreton (1991) modelled uncertainty using the standard deviation across 12 forecasting teams of the output growth and inflation rate over the next 12 months. They found a negative long-run effect from output growth uncertainty on investment but no long-run effect from inflation uncertainty on investment. Darby et al. (1999) employed the Kenen-Rodrick (1986) approach of a moving average of the variance. A further issue is the *specification of the investment function*. One key empirical finding of Leahy and Whited (1996) was that uncertainty proxies may be irrelevant in the presence of Tobin's Q.

Looking specifically at work on *exchange rate uncertainty*, empirical evidence for a negative effect of exchange rate volatility on investment is provided inter alia by Goldberg (1993) for the US (using rolling standard deviations) and Darby et al. (1999) for the G7 estimated country-by-country (using the Kenen-Rodrick method outlined above). In the latter paper, long run investment in Germany and France was found to be negatively affected by exchange rate uncertainty, whilst there was weaker evidence for Italy and the UK and none for the US. More recent work by Darby et al. (2002) concentrated on the impact of exchange rate misalignment on investment and found evidence of non-linearities and asymmetries. They used a different measure of uncertainty, which extracts the trend component of the real exchange rate before calculating volatility. They found that volatility in the US then has a positive effect. This underlines the fact that the method of extracting volatility is important empirically.

Byrne and Davis (2002) provided evidence for similarities across the G7 in the negative response of investment to uncertainty in nominal and real effective exchange rates estimated using GARCH and Pooled Mean Group Panel Estimation. This was also found in poolable subgroups including all four larger EU countries. The authors noted that to the extent EMU favours lower exchange rate and long rate volatility, it is implied to be beneficial to investment. In complementary work, Serven (2003) using GARCH measures of uncertainty, found that real exchange rate uncertainty has a highly significant impact on investment using evidence from the developing countries. The impact was larger at higher levels of uncertainty – in line with analytical literature underscoring 'threshold effects'. Moreover, the investment effect of real exchange rate uncertainty was 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.

The literature on exchange rate uncertainty and investment has been extended by recent studies such as Nucci and Pozzolo (2001) who presented results where permanent changes in the exchange rate are important for the level of investment whilst changes in the transitory component are not. However, they used a specific method of decomposing exchange rate changes (Beveridge and Nelson 1981) whose outcome suggested that the variance of the change in the transitory component made a minor contribution to overall volatility. Recent theoretical work by Baum et al. (2001) investigated the impact of the permanent and transitory components of exchange rate uncertainty on firms' profits. They suggested that it is difficult to identify the effect of volatility of the exchange rate on *growth* in profits, since the effect of a positive change in exchange rates will be different from a negative change.[2] On the other hand there is an unambiguous result that a rise in volatility of the permanent component will boost profit *volatility* (as firms act to take advantage of related permanent shifts in the exchange rate) while a rise in temporary volatility will dampen it (as firms become more conservative under heightened uncertainty). We suggest that a corollary could be that investment is broadly maintained if there are shifts in permanent volatility (i.e. the firm "acts" to invest in a way to maximise profits in the new situation) while in the case of temporary volatility there may be inertia and a fall in investment from the level predicted by other macroeconomic variables. Such a pattern is shown in terms of the first moment of the interest rate by Moore and Shaller (2002) who assessed the impact of transitory and permanent interest rate shocks on investment where firms seek to learn about persistent changes in a way that is influenced by the pattern of noise generated by transitory shocks.

Empirically, a differential impact from long run and short run uncertainty in *prices* on investment was emphasised by Chadha and Sarno (2002). They found evidence of a clear link between uncertainty in the price level and investment. Moreover, they found that short-run uncertainty is more important in determining real activity than long-run uncertainty. This point was also raised by Ball and Cecchetti (1990) when considering the impact of uncertainty in inflation on the level of inflation itself. Darby et al. (1999)

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[2] We accommodate this by incorporating income into our regression analysis: any effect of a permanent devaluation should feed through that variable. We also test directly for uncertainty measures with asymmetries via use of EGARCH.

examined the impact of deviations from equilibrium relationships as important factors underlying the response of investment to the effective exchange rate.

2.4 Volatility Measurement

As noted above, there are a numbers of ways of modelling the impact of uncertainty on investment. These include simple rolling standard deviations or variance, and time series conditional heteroscedastic methods. Engle (1982) introduced the ARCH methodology which was later extended to incorporate a lagged dependent variable in the conditional variance (GARCH). This method is presumed to capture risk in each period more sensitively that simple rolling standard deviations, which give equal weight to correlated shocks and single large outliers. As noted above, GARCH methods have been used to derive measures of uncertainty and numerous studies have found a relationship between the resultant variable and investment.

As set out in Bollerslev (1986), GARCH (p,q) models are of the form,

$$v_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i v_{t-i} \tag{4}$$

where ε_t is serially uncorrelated with mean zero, but the conditional variance of ε_t equals v_t, which may be changing through time. In most applications, ε_t refers to the innovation in the mean for some other stochastic process, say $\{y_t\}$ where

$$y_t = g(x_{t-1};\beta) + \varepsilon_t \tag{5}$$

and $g(x_{t-1};\beta)$ denotes a function of x_{t-1} and the parameter vector β, where x_{t-1} is in the time *t-1* information set.

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) process this amounts to ensuring that both α_1 and β_1 are non-negative. It follows also that ε_t is covariance stationary if and only if $\alpha_1+\beta_1<1$.

An interesting development of the basic GARCH model is the so-called components GARCH (CGARCH) of Engle and Lee (1999). They set out the GARCH(1,1) model as characterised by reversion to a constant mean ($\overline{w}$):

$$\sigma_t^2 = \overline{w} + \alpha_1\left(\varepsilon_{t-1}^2 - \overline{w}\right) + \beta_1\left(\sigma_{t-1}^2 - \overline{w}\right) \tag{6}$$

The components model allows reversion to a varying mean q_t using an autoregressive term ρ, modelled as

$$\sigma_t^2 - q_t = \overline{w} + \alpha_1\left(\varepsilon_{t-1}^2 - \overline{w}\right) + \beta_1\left(\sigma_{t-1}^2 - \overline{w}\right) \tag{7}$$

$$q_t = \alpha_0 + \rho\left(q_{t-1} - \alpha_0\right) + \phi\left(\varepsilon_{t-1}^2 - \sigma_{t-1}^2\right) \tag{8}$$

Equation (7) defines the temporary component ($\sigma_t^2 - q_t$), whilst equation (8) is the permanent equation. When $0 < \left(\alpha_1 + \beta_1\right) < 1$, short run volatility converges to its mean of 0, while if $0 < \rho < 1$ the long run component converges to its mean of $\alpha_0/(1-\rho)$. As the long run volatility is more persistent than the short run, it is also assumed that $0 < (\alpha_1 + \beta_1) < \rho < 1$. For negative variance to be ruled out, sufficient conditions are that α_1, β_1 and α_0 are positive and that $\beta_1 > \varphi > 0$.

An objection to both GARCH and CGARCH is that they assume symmetry between positive and negative shocks in terms of their effect on conditional volatility. For example, it is plausible that a negative shock to exchange rates gives rise to higher uncertainty as it could entail heightened expectations of a speculative attack.

The Exponential GARCH model was introduced by Nelson (1991) with the following specification.

$$\log\sigma_t^2 = w + \beta\log\sigma_{t-1}^2 + \alpha\left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right| + \gamma\frac{\varepsilon_{t-1}}{\sigma_{t-1}} \tag{9}$$

Hence the EGARCH describes the relationship between the past shocks and the log of the conditional variance. Since it is specified in logs, no parameter restrictions have to be imposed to ensure that the conditional variance is non-negative. Negative shocks have an impact of $\alpha - \gamma$ on the log of the conditional variance and positive shocks have an effect of $\alpha + \gamma$. Hence there is an asymmetry if $\gamma \neq 0$. For example, if $\gamma < 0$, $0 < \alpha < 1$ and $\alpha + \beta < 1$, negative shocks have a larger effect on conditional variance than positive shocks of the same size.

2.5 Panel Estimation

The impact of uncertainty on investment is usefully captured in a cross-country sample by using Pesaran, Shin and Smith's (1999) Pooled Mean Group Estimator (PMGE) for dynamic heterogeneous panel models. Panel methods have become popular in cross sectional macro data sets, since they provide greater power that individual country studies and hence greater efficiency.

Pesaran et al. emphasised that there are two traditional methods when 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 suggested 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, pooling the data typically assumes that the slope coefficients and error variances are identical. This is unlikely to be valid for short-run dynamics and error variances, although it could be appropriate for the long run.

Pesaran et al. (1999) proposed the PMGE method, which is an intermediate case between the averaging and pooling methods of estimation, and involves aspects of both. The PMGE method restricts the long-run coefficients to be equal over the cross-section, but allows for the short-run coefficients and error variances to differ across groups on the cross-section. We can therefore obtain pooled long-run coefficients and averaged short run dynamics as an indication of mean reversion.

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 $\mathbf{x}_{it}$ (kx1) 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 (kx1) 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 *i.i.d.* 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

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

The long-run homogeneous coefficient is equal to $\theta = \theta_i = -(\beta_i' / \phi_i)$, 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. The estimated coefficients in the model are not dependent upon whether the variables are I(1) or I(0). The key feature of the PMGE is to make the long-run relationships homogenous while allowing for heterogeneous dynamics and error variances.

2.6 Specification

Drawing on the insights provided in the discussion of Sections 2.1-2.5, we estimated the impact of exchange rate uncertainty in a neoclassical investment function which also allows in variants for the influence of Tobin's Q. Estimation was carried out using Pooled-Mean-Group estimation with exchange-rate uncertainty proxies estimated by CGARCH and EGARCH. As a baseline, we first set out the main result of Byrne and Davis (2002) using a simple GARCH (1,1) approach. This was itself a considerable advance on previous work for adopting the PMGE approach and testing for poolability. We sought to further refine the approach to investment and exchange rate uncertainty, adopting the insights of Chadha and Sarno (2002) by decomposing uncertainty into a permanent and transitory component. However, our approach uses the Engle and Lee (1999) approach to modelling GARCH, in contrast to the methods of Chadha and Sarno (2002) who utilise a unobserved components model and maximum likelihood estimation to identify the permanent and temporary aspects of price uncertainty. The authors also consider their methods in terms of single equation estimation for each country, and we try to move beyond this with panel estimation. Finally, we focus on exchange rate uncertainty, whereas Chadha and Sarno look at price level uncertainty. Additionally we consider the point raised by Baum et al. (2001) that there could be asymmetries from exchange rate uncertainty depending on whether they link to an appreciation or depreciation. We do this by employing the EGARCH approach of Nelson (1991), which allows for such asymmetries in conditional volatility generation from positive and negative shocks.

In our estimation, besides using PMGE, 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. We test for long-run homogeneity using a joint Hausman test based on the null of equivalence between the PMG and MG estimation (see Pesaran, Smith and Im, 1996, for details). If we reject the null (obtain a probability value of less that 0.05), we reject homogeneity of our cross section's long run coefficients. Significant statistical difference between our two estimators would be indicative of panel misspecification.[3] The likelihood ratio test for long run parameter heterogeneity is much more conventional in this setting and has homogeneity as the null hypothesis (see Hsiao, 1986).

3. Results

3.1 Data

The main source of data for the G7 countries is the OECD Business Sector Database. A typical problem with private sector investment data is the distortion caused by transfer of ownership e.g. in privatisations. Our quarterly OECD data set circumvents this problem by incorporating business investment and output irrespective of ownership. Our monthly effective exchange rate data is obtained from Primark Datastream. As shown in Appendix A, all the macroeconomic variables, namely investment, output and Tobin's Q are non stationary according to Elliott, Rothemberg and Stock (1996) and Ng and Perron's (2001) feasible point optimal test and the modified point optimal test. The GARCH outturns also were generally seen as non-stationary, albeit to an extent that depended upon the lag length in the unit root tests as determined by the modified AIC tests. A similar result was found by Ng and Perron (2001) for inflation. The non-stationary properties of the data suggest an error correction approach to modelling investment is appropriate, so long as cointegration is present.

3.2 GARCH estimation

The results for the CGARCH are presented in Table 1 below. It can be seen that the transitory equations are fairly conventional, with significant positive ARCH terms of 0.07-

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[3] Pesaran and Smith (1995) illustrate that traditional approaches to estimation of pooled models (e.g. fixed effects, IV and generalised method of moments) produce potentially misleading coefficient estimates for

0.43. The GARCH terms in the transitory equations are more variable, with those for the UK and Germany being insignificant and that for Japan being negative. Stability of short run volatility is established (the sum of coefficients being between zero and one) except for Japan. As regards the determinants of the long run component, there is a positive constant, which is significant except for Italy, and a very large autoregressive component, implying slow convergence of permanent volatility on its mean level. The size of the autoregressive component exceeds that of the transitory components, implying slower mean reversion in the long run. The component is below one in all cases, implying the process is stable. Finally the permanent ARCH less GARCH term is significant except in the US and is negative in Canada and France, positive elsewhere,

Table 1: Components GARCH estimate for nominal effective exchange rate

	UK	US	Germany	Japan	Canada	France	Italy
Perm: Constant (α_0)	**0.00177 (0.295)**	**0.0004 (5.168)**	**0.0001 (10.148)**	0.00118 (1.189)	**0.000112 (9.427)**	**0.0000346 (4.465)**	0.0041 (0.281)
Perm [q- α_0] (ρ)	**0.998 (969.623)**	**0.993 (740.677)**	**0.934 (28.330)**	**0.997 (513.209)**	**0.981 (257.540)**	**0.995 (6149.583)**	**0.998 (204.582)**
perm [arch-garch] (φ)	**0.043 (2.470)**	-0.041 (0.997)	0.027 (0.793)	**0.022 (12.595)**	**-0.053 (3.042**	**-0.027 (2.837)**	**0.243 (4.045)**
Tran [arch-q] (α)	**0.37 (6.076)**	**0.089 (1.954)**	**0.132 (2.396)**	**0.179 (3.709)**	**0.0973 (2.399)**	**0.339 (7.473)**	**0.334 (6.268)**
Tran [garch-q] (β)	0.168 (1.239)	**0.877 (22.878)**	0.417 (1.597)	**-0.27 (2.046)**	**0.725 (9.180)**	-0.016 (0.138)	**0.402 (4.536)**

Notes: T-statistics are in parentheses. Bold indicates significance at 5%.

Table 2: Exponential GARCH estimate for nominal effective exchange rate

	UK	US	Germany	Japan	Canada	France	Italy
Constant (w)	**-1.4 (6.505)**	**-0.375 (6.249)**	**-2.7 (4.383)**	**-0.141 (252.989)**	**-0.75 (5.057)**	**-8.7 (4.511)**	**-2.77 (11.273)**
Absolute (res/garch) (α)	**0.485 (7.797)**	**0.06 (2.295)**	**0.354 (7.245)**	**-0.064 (9.253)**	0.038 (0.763)	**0.39 (6.295)**	**0.998 (24.614)**
(res/garch) (γ)	-0.064 (1.520)	-0.005 (0.290)	**0.107 (3.070)**	**-0.057 (3.591)**	**-0.079 (2.369)**	0.064 (1.225)	-0.0089 (0.230)
EGARCH (β)	**0.875 (39.076)**	**0.96 (182.938)**	**0.74 (11.175)**	**0.974 (1636.8)**	**0.922 (69.3712)**	0.086 (0.422)	**0.775 (31.391)**

Notes: T-statistics are in parentheses. Bold indicates significance at 5%

implying a possibility of negative volatility in those countries. The charts appended show the estimated transitory and permanent components of volatility for the G7 countries.[4]

The results for the EGARCH are given in Table 2. We noted above that there are no required constraints on signs for avoiding negative volatility, since the specification is

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large T, unless cross section coefficients are identical.

set out in logs. In fact asymmetric effects are only significant in Germany, Japan and Canada. In Japan and Canada it is negative shocks that give rise to heightened volatility and in Germany it is appreciation (probably a reflection of ERM crises when the DM was under upward pressure – and thus consistent with depreciation in the UK, France and Italy).

3.3 Panel Estimation

We now go on to present the results of PMGE and MGE estimation. The Likelihood Ratio (LR) test statistic and the Hausman test statistic (both distributed as χ^2) examine panel heterogeneity. The LR statistic always suggests that homogeneity is not a reasonable assumption in the Pesaran et al. (1999) 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). Accordingly, we focus largely on the LR test in the following results.

As a baseline, Table 3 replicates the result of Byrne and Davis (2002) using GARCH (1,1). Columns 1 and 2 show the results for PMG and MGE estimation of the long run components of our basic investment function in the G7 with nominal exchange rate uncertainty effects. We show estimated long run coefficients of business output, ln(YB), the conditional variance of the nominal effective exchange rate, estimated error correction terms, the Likelihood Ratio and Hausman statistics. In the equation, the long run elasticity on output is significant and the estimated coefficient is slightly larger than one in magnitude. Also, the error correction term is significant and gives evidence of mean reversion to a long-run relationship and cointegration. The user cost was omitted as insignificant. In terms of the measures of volatility, we find that the measure of nominal exchange rate uncertainty is significant in influencing long-run business investment across the G7 with a PMG estimated elasticity of –8.018. We see from the probability values associated with the Hausman test of equivalence of PMG and MG that it accepts (p-value > 0.05) and hence, according to this test there is parameter homogeneity across the G-7 as a whole. However, we cannot accept parameter homogeneity for the LR test for the G-7 (test statistic $\chi^2\{12\} = 30.72$, whilst the critical value is 21.03). This suggests a need to focus on

[4] The quarterly conditional volatility time series is based on the last month of each quarter. Alternative methods were tried and did not materially effect the results.

subgroups, and indeed as shown in columns 4 and 5, the EU-4 of the UK, France, Germany and Italy do allow for pooling as well as having a significant exchange rate effect.

Table 3: PMG Estimation of Investment and Exchange Rate Uncertainty: G7 and EU4 Countries

	PMGE	MGE	PMGE	MGE
	G7		**EU4**	
Ln(YB)	**1.346 (24.944)**	**1.439 (11.637)**	**1.233 (21.371)**	**1.202 (63.534)**
CV(DER)	**-8.018 (2.887)**	**-25.198 (2.097)**	**-11.808 (3.312)**	**-12.670 (2.852)**
Error Correction	**-0.077 (5.270)**	**-0.083 (4.431)**	**-0.094 (3.855)**	**-0.097 (4.578)**
Likelihood (Unrestricted)	1652.252 (1667.613)		935.335 (937.006)	
LR Statistic χ^2 {df}	**30.72 {12} [p=0.00]**		4.19 {6} [0.65]	
Hausman χ^2 {df}	3.44 {12} [0.18]		Na	

Notes: Dependent variable Business Investment. PMGE is Pooled Mean Group Estimation. MGE is Mean Group Estimation. Sample period 1973Q1 to 1996Q4. T statistics are in parentheses. P-values are in square brackets. The lag structure is determined by the Schwarz Bayesian Criteria. The LR Statistic is a likelihood ratio test for the null hypothesis of poolability. Hausman test for poolability 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. CV(.) is the conditional variance from GARCH (1,1) estimation. DER is the log first difference of the nominal effective exchange rate.

Table 4: PMG Estimation of Investment and Exchange Rate Uncertainty: G7 Countries

	PMGE	MGE	PMGE	MGE	PMGE	MGE
ln(YB)	**1.347 (26.881)**	**1.240 (22.196)**	**1.359 (26.178)**	**2.347 (2.510)**	**1.333 (24.685)**	**1.339 (10.480)**
CV(PERM)	261.184 (1.378)	1334.829 (0.796)			**679.584 (2.243)**	1190.854 (0.647)
CV(TEMP)			-150.574 (1.677)	-6383.884 (1.166)	**-372.750 (2.627)**	-759.049 (1.701)
Error Correction	**-0.082 (5.946)**	**-0.082 (5.314)**	**-0.080 (5.840)**	**-0.082 (4.23)**	**-0.079 (4.808)**	**-0.079 (4.197)**
Likelihood (Unrestricted)	1653.899 (1669.610)		1652.139 (1670.381)		1652.565 (1675.343)	
LR Statistic χ^2 {df}	**31.442 [0.002]**		**36.484 [0.000]**		**38.424 [0.003]**	
Hausman Test χ^2 {df}	Na		3.35 [0.19]		**25.04 [0.00]**	

Notes: See Table 3, also CV (PERM) represents permanent component from CGARCH, CV (TEMP) the corresponding transitory component. These results are for the G7: the US, Canada, Japan, Italy, France, Germany and the UK. Sample period 1973Q1 to 1996Q4.

Table 4 shows the results in the G7 of the estimation of separate components of the CGARCH separately and together.[5] The results show that neither transitory nor permanent volatility entered separately has a significant effect on investment, although there is some evidence of a negative effect from the transitory component at the 10% significance level.

[5] The stationarity properties of the data are considered in appendix A. Typically all variables are I(1) and the small amount of evidence of stationarity is not unexpected give the large number of tests we conduct.

When entered together, both components are significant with permanent shocks having a positive sign and only temporary shocks the expected negative one. There is evidence of

Table 5: PMG Estimation of Investment and Exchange Rate Uncertainty: EU4 Countries

	PMGE	MGE	PMGE	MGE	PMGE	MGE
ln(YB)	**1.271 (22.580)**	**1.138 (50.089)**	**1.278 (22.414)**	**1.237 (33.833)**	**1.271 (22.723)**	**1.112 (37.707)**
CV(PERM)	-168.268 (0.697)	-1289.439 (0.949)			405.740 (1.216)	-1132.884 (0.555)
CV(TEMP)			**-361.123 (-2.343)**	-614.115 (-1.863)	**-375.786 (2.326)**	-218.134 (-0.852)
Error Correction	**-0.103 (4.090)**	**-0.092 (4.416)**	**-0.095 (-3.997)**	**-0.098 (-4.574)**	**-0.104 (-3.823)**	**-0.093 (-4.081)**
Likelihood (Unrestricted)	935.339 (941.227)		931.234 (936.887)		931.722 (941.676)	
LR Statistic χ^2 {df}	11.777{6} [0.067]		11.305{6} [0.079]		14.371 {9} [0.110]	
Hausman χ^2 {df}	Na		Na		Na	

Notes: See Table 3, also CV (PERM) represents permanent component from CGARCH, CV (TEMP) the corresponding transitory component. These results are for France, Germany, Italy and the UK. Sample period 1973Q1 to 1996Q4.

poolability on the basis of the Hausman test. However, cross sectional parameter equivalence is not accepted by the LR test and this encourages to further examine the poolability of the countries based on this statistic for a smaller panel.

On the basis of the relevance for EMU, our CGARCH results and also the pooling results above, we then focused our attention on nominal exchange rate volatility in the EU4 of the UK, Italy, France and Germany. Table 5 shows the results and we see that for the temporary component alone the t-value is significant and also when the temporary and permanent components are entered together. Permanent volatility is everywhere insignificant. Concerning poolability, this is accepted with the LR test for all results including temporary and permanent together (columns 6 and 7). Temporary volatility in these investment functions can be viewed as generating uncertainty about future exchange rates, which may relate in turn to short term speculative pressures. On the other hand permanent volatility characterises periods of change in the exchange rate required by fundamental macroeconomic adjustments, which are likely to take much longer. Permanent volatility does not appear to be an inhibitor of investment, as noted above, rather it may be that investment plans are still carried out in the new market situation – or even accelerated to take advantage of the competitive opportunities (as witness positive signs in Table 4). Contrast this with short run volatility driven by market conditions, the kind removed by a permanently fixed exchange rate regime, which does inhibit business investment owing to related uncertainty.

Table 6: PMG Estimation of Investment and Exchange Rate Uncertainty: EU4 Countries with Tobin's Q

	PMGE	MGE	PMGE	MGE	PMGE	MGE
ln(YB)	**1.250 (18.783)**	**1.266 (5.884)**	**1.238 (17.715)**	**1.144 (8.558)**	**1.252 (18.887)**	**1.016 (5.697)**
TOBIN'S Q	0.067 (0.572)	-0.268 (-0.950)	0.159 (0.949)	-0.093 (-0.501)	0.060 (0.528)	0.019 (0.112)
CV(PERM)	-188.251 (0.752)	86.718 (0.969)			384.593 (1.127)	-1171.790 (-0.555)
CV(TEMP)			**-453.762 (-2.437)**	-603.640 (-1.848)	**-381.142 (-2.296)**	-234.478 (-0.820)
Error Correction	**-0.101 (-4.108)**	**-0.099 (-4.136)**	**-0.089 (-3.695)**	**-0.096 (-4.742)**	**-0.102 (-3.883)**	**-0.090 (-4.219)**
Likelihood (Unrestricted)	935.521 (942.239)		931.744 (938.559)		939.488 (948.202)	
LR Statistic χ^2 {df}	13.434{9} [0.14]		13.629{9} [0.14]		17.428 {12} [0.13]	
Hausman χ^2 {df}	Na		Na		Na	

Notes: See Table 3, also CV(PERM) represents permanent component from CGARCH, CV(TEMP) the corresponding transitory component. The EU4 consists of France, Germany, Italy and the UK.

We then sought to assess a variant on these results including Tobin's Q in the estimation, also to test the empirical finding of Leahy and Whited (1996) that uncertainty proxies may be irrelevant in the presence of Q (Table 6). In fact the transitory component remains significant, while poolability is again suggested for all the specifications. Tobin's Q itself is not significant, a result which contrasts with the G7 results shown in Byrne and Davis (2002).

In our final set of results we investigated whether the inclusion of the EGARCH conditional variance, allowing for asymmetric responses of conditional volatility to change in the exchange rate, made a difference to the results. Bear in mind that, as shown in Table 2, the significant asymmetries only arise for Japan, Canada and Germany. Table 7 shows results with and without Q for the G7; we find that an asymmetric measure of GARCH is significant but there is no evidence for poolability

We undertook similar estimation for the EU-4 where the difference from basic GARCH will arise mainly from responses of German investment to volatility following exchange rate appreciation (Table 8). In the basic case the nominal exchange rate is significant but poolability is not indicated. However, when Tobin's q is added we also accept poolability.

Table 7: Panel Estimation of Investment and Uncertainty: G7 Countries EGARCH

	PMGE	MGE	PMGE	MGE
Ln(YB)	**1.465 (21.859)**	**1.239 (6.224)**	**1.310 (22.864)**	**0.962 (3.722)**
TOBIN'S Q			**0.265 (2.998)**	0.616 (1.295)
CV(DER)	**-280.845 (-2.484)**	-131.376 (-0.104)	**-307.296 (-2.771)**	216.84 (0.144)
Error Correction	**-0.069 (-5.979)**	**-0.076 (-3.434)**	**-0.074 (-5.229)**	**-0.081 (-3.558)**
Likelihood (Unrestricted)	1646.136 (1667.913)		1649.387 (1679.189)	
LR Statistic χ^2 {df}	**43.555 {12} [0.00]**		**59.604{18} [0.00]**	
Hausman χ^2 {df}	**7.86 {12} [0.02]**		**18.30 {18} [0.00]**	

Notes: Dependent variable Business Investment. PMGE is Pooled Mean Group Estimation. MGE is Mean Group Estimation. Sample period 1973Q1 to 1996Q4. T statistics are in parentheses. P-values are in brackets. The lag structure is determined by the Schwarz Bayesian Criteria. The LR Statistic is a likelihood ratio test for the null hypothesis of poolability. Hausman test for poolability 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. CV(.) is the conditional variance from EGARCH estimation. DER is the first difference of the nominal effective exchange rate.

Table 8 Panel Estimation of Investment and Uncertainty: EU4 Countries EGARCH

	PMGE	MGE	PMGE	MGE
Ln(YB)	**1.273 (23.296)**	**1.216 (25.579)**	**1.188 (15.552)**	**1.091 (7.547)**
TOBIN'S Q			0.262 (1.193)	-0.034 (-0.195)
ECV(DER)	**-294.348 (-2.213)**	-1070.079 (-1.574)	**-644.395 (-2.287)**	-1096.323 (-1.605)
Error Correction	**-0.097 (-3.582)**	**-0.096 (-4.395)**	**-0.078 (-2.808)**	**-0.092 (-4.685)**
Likelihood (Unrestricted)	931.898 (938.482)		932.046 (940.417)	
LR Statistic χ^2 {df}	**13.168{6} [0.040]**		16.743 {9} [0.053]	
Hausman χ^2	Na		Na	

Notes: Dependent variable Business Investment. PMGE is Pooled Mean Group Estimation. MGE is Mean Group Estimation. Sample period 1973Q1 to 1996Q4. T statistics are in parentheses. P-values are in brackets. The LR Statistic is a likelihood ratio test for the null hypothesis of poolability. Hausman test for poolability is a test for the equivalence of PMGE and MGE. ECV(.) is the conditional variance from EGARCH estimation. DER is the first difference of the nominal effective exchange rate. EU4 represents France, Germany, Italy and the UK.

4. Conclusion

In this paper we have sought to shed light on the importance of exchange rate uncertainty for business investment at a macroeconomic level. In particular, we have estimated the impact on investment of temporary and permanent components of exchange rate uncertainty derived using a components GARCH model. Additionally we have considered asymmetric responses to exchange rate changes using an EGARCH. The key result is that for a poolable subsample of EU countries, it is the transitory and not the permanent component which adversely affects investment. This is consistent with an adaptation of the suggestion in Baum et al. (2001) regarding profitability, namely, that permanent volatility will not hinder investment as firms act to take advantage of related permanent shifts in the exchange rate - while a rise in temporary volatility will dampen investment as firms become more conservative under heightened uncertainty and delay their investment. Or, following Moore and Schaller (2002), the different impact of persistent and temporary economic shocks on investment decisions may be due to the evolution of beliefs under learning.

The results imply that to the extent that EMU favours lower transitory exchange rate volatility, it will also be beneficial to investment. EMU after all eliminates short run volatility among the component currencies, linked inter alia to currency speculation, that was rife in the ERM. Equally, there is some support for asymmetries in response of uncertainty to shocks in Germany, Japan and Canada, and the results for investment functions suggest that the conditional variances derived are successful in an investment function specification for the EU-4 including Tobin’s Q.

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Table A1 Unit Root Tests Components GARCH Permanent and Temporary Conditional Volatility

		US	CA	FR	GE	IT	JP	UK
Ln(IB)	**k**	1	2	0	0	2	2	0
(trend)	**AR(α):**	0.925	0.943	0.965	0.964	0.923	0.961	0.947
	ERS Pt	6.534	9.921	30.981	34.608	7.761	9.39	20.619
	M Pt	6.592	8.869	28.389	28.895	7.84	8.472	18.854
Ln(YB)	**k**	1	1	2	0	1	3	3
(trend)	**AR(α):**	0.919	0.945	0.942	0.97	0.946	0.942	0.963
	ERS Pt	8.528	9.917	9.347	35.442	11.009	8.764	15.751
	M Pt	7.83	9.341	8.855	32.837	9.31	8.28	12.957
Tobin's Q	**k**	0	4	6	2	1	4	2
(trend)	**AR(α):**	0.99	0.948	0.98	0.988	0.917	0.97	0.955
	ERS Pt	65.784	10.809	64.417	40.762	8.448	16.945	27.892
	M Pt	51.038	9.075	54.514	35.741	8.623	16.063	21.385
Ln(IB)	**k**	1	1	2	0	1	3	3
(constant)	**AR(α):**	0.919	0.945	0.942	0.97	0.946	0.942	0.963
	ERS Pt	8.528	9.917	9.347	35.442	11.009	8.764	15.751
	M Pt	7.83	9.341	8.855	32.837	9.31	8.28	12.957
Ln(YB)	**k**	9	3	12	4	11	4	4
(constant)	**AR(α):**	1.003	1.005	1.002	1.006	1.001	1.001	1.005
	ERS Pt	36.351	114.525	72.892	67.288	38.025	27.053	56.244
	M Pt	28.302	84.843	54.207	53.91	27.687	20.927	46.814
Tobin's Q	**k**	0	4	11	2	7	4	2
(constant)	**AR(α):**	0.992	0.963	1.008	0.983	0.972	0.974	0.983
	ERS Pt	25.957	3.824	35.481	17.76	11.129	5.229	12.373
	M Pt	22.201	3.707	31.705	14.904	9.732	5.311	12.544

Notes: ***K*** is the lag length determined by the Modified AIC, see Ng and Perron (2001). Sample period 1973Q1 1996Q4. AR(α) is the estimated autoregressive coefficient. All variables have been detrended by GLS for both the statistic and spectral density. Estimated statistics in bold indicate stationarity. ERS Pt is the Elliott, Rothemberg and Stock (1996) feasible point optimal test. M Pt is the modified point optimal test. 5% critical value is 5.48 for case with trend. 5% Critical Value is 3.17 with constant. Test statistics of less than the critical value reject the null hypothesis of unit root.

Table A2 Unit Root Tests Components GARCH Permanent and Temporary Conditional Volatility -Trend

		US	CA	FR	GE	IT	JP	UK
CV(NEER)	**k**	6	7	1	5	11	0	1
(trend)	**AR(α):**	0.911	0.610	0.915	0.722	0.491	0.931	0.785
Permanent	**ERS Pt**	141.630	36.435	18.543	23.263	12.889	15.173	6.995
	M Pt	107.410	33.669	15.791	23.591	12.922	14.636	6.484
CV(NEER)	**k**	5	5	12	9	9	6	4
(trend)	**AR(α):**	0.879	0.602	0.793	0.499	0.615	0.845	0.282
Temporary	**ERS Pt**	17.533	8.608	192.901	122.701	17.597	84.182	**4.077**
	M Pt	17.845	8.774	175.514	123.644	17.945	66.216	**4.142**
CV(NEER)	**k**	1	4	5	9	9	6	3
(trend)	**AR(α):**	0.884	0.796	0.817	0.615	0.607	0.791	0.330
total	**ERS Pt**	9.805	9.849	41.548	137.853	15.413	48.247	**4.168**
	M Pt	9.671	9.974	35.877	139.030	15.657	40.864	**4.248**

Notes: ***K*** is the lag length determined by the Modified AIC see Ng and Perron (2001). Sample period 1973Q1 1996Q4. Alpha-hat is the estimated autoregressive coefficient. All variables have been detrended by GLS for both the statistic and spectral density. Estimated statistics in bold indicate stationarity. ERS Pt is the Elliott, Rothemberg and Stock (1996) feasible point optimal test. M Pt is the modified point optimal test. 5% Critical Value 5.48. Test statistics of less than the critical value reject the null hypothesis of unit root.

Table A3 Unit Root Tests Components GARCH Permanent and Temporary Conditional Volatility -Constant

		US	CA	FR	GE	IT	JP	UK
CV(NEER)	**k**	6	7	1	5	11	0	1
(constant)	**AR(α):**	1.010	0.908	1.008	0.914	0.770	0.998	0.934
Permanent	**ERS Pt**	179.375	25.143	86.098	12.380	13.303	37.104	8.263
	M Pt	118.162	24.986	60.577	11.372	12.063	27.166	5.988
CV(NEER)	**k**	5	5	5	9	9	6	1
(constant)	**AR(α):**	0.880	0.946	0.946	0.807	0.684	0.989	0.147
Temporary	**ERS Pt**	4.970	18.278	31.476	62.383	6.848	104.892	**0.995**
	M Pt	5.048	14.880	23.069	62.773	6.754	70.210	**0.988**
CV(NEER)	**k**	1	4	5	7	9	5	3
(constant)	**AR(α):**	0.922	0.988	1.012	0.779	0.724	0.871	0.336
Total	**ERS Pt**	4.308	27.154	77.956	14.608	7.601	18.788	**1.921**
	M Pt	3.739	22.276	53.960	14.502	7.282	14.666	**1.801**

Notes: ***K*** is the lag length determined by the Modified AIC see Ng and Perron (2001). Sample period 1973Q1 1996Q4. Alpha-hat is the estimated autoregressive coefficient. All variables have been detrended by GLS for both the statistic and spectral density. Estimated statistics in bold indicate stationarity. ERS Pt is the Elliott, Rothemberg and Stock (1996) feasible point optimal test. M Pt is the modified point optimal test. 5% Critical Value 3.17. Test statistics of less than the critical value reject the null hypothesis of unit root.

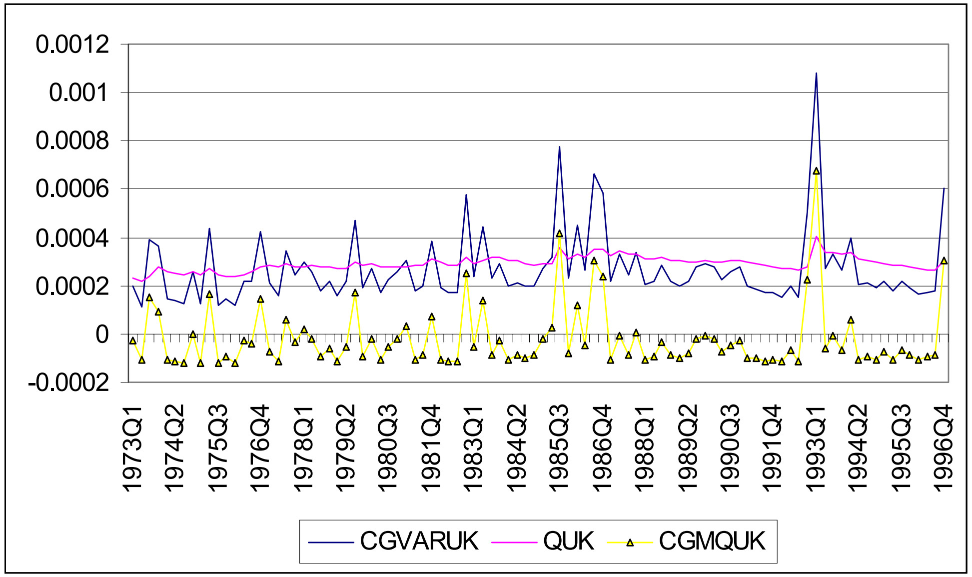
Table A4 Unit Root Tests : Asymmetric GARCH (EGARCH)

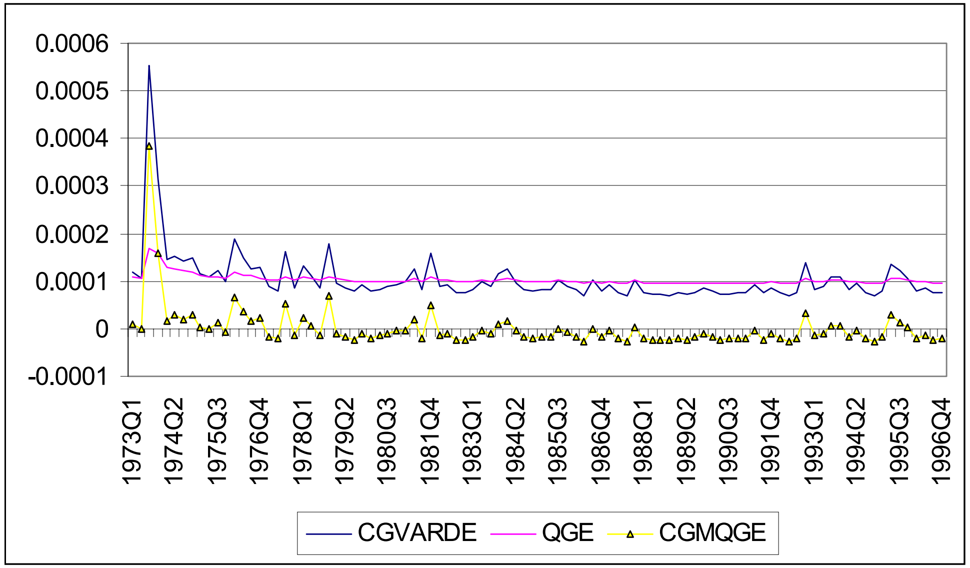
		US	CA	FR	GE	IT	JP	UK
ECV(NEER)	**k**	0	2	10	11	9	0	0
(trend)	**AR(α):**	0.965	0.834	0.906	0.615	0.739	0.881	0.460
	ERS Pt	27.705	9.862	235.484	197.344	31.808	9.854	**2.465**
	M Pt	24.090	9.262	181.575	199.943	32.026	8.749	**2.511**
ECV(NEER)	**k**	0	2	11	10	9	0	0
(constant)	**AR(α):**	0.984	0.950	1.015	0.851	0.886	0.980	0.455
	ERS Pt	25.054	9.626	967.020	60.855	19.584	16.060	**0.705**
	M Pt	17.832	7.204	640.281	59.440	17.617	11.268	**0.710**

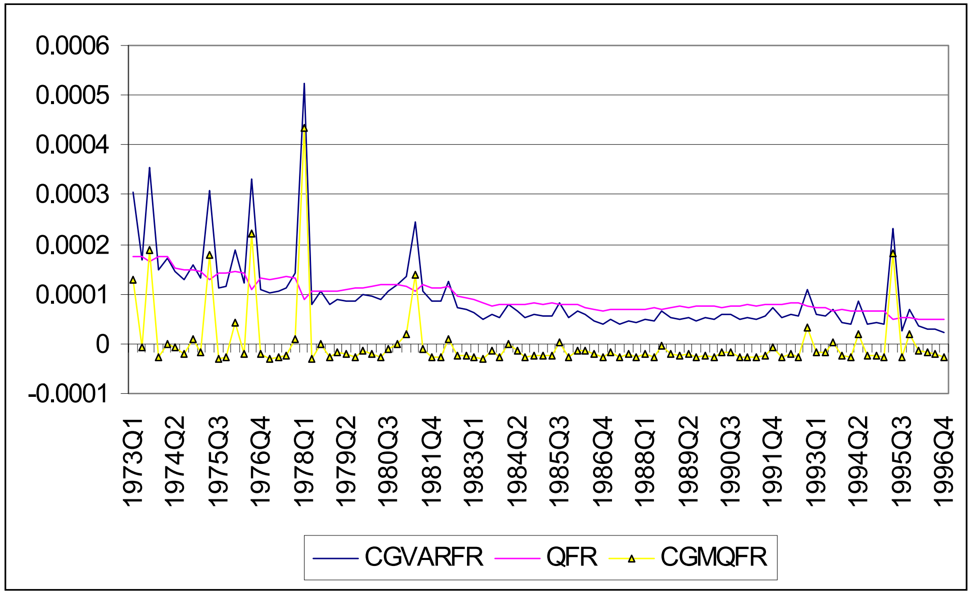
Notes: ***K*** is the lag length determined by the Modified AIC see Ng and Perron (2001). Sample period 1973Q1 1996Q4. Alpha-hat is the estimated autoregressive coefficient. All variables have been detrended by GLS for both the statistic and spectral density. Estimated statistics in bold indicate stationarity. ERS Pt is the Elliott, Rothemberg and Stock (1996) feasible point optimal test. M Pt is the modified point optimal test. 5% critical value is 5.48 for case with trend. 5% Critical Value is 3.17 with constant. Test statistics of less than the critical value reject the null hypothesis of unit root.

Figure B1 Total (CGVAR), Transitory (CGMQ) and Permanent component measures of volatility for G7

Key UK: United Kingdom; DE: Germany; IT: Italy; FR: France.







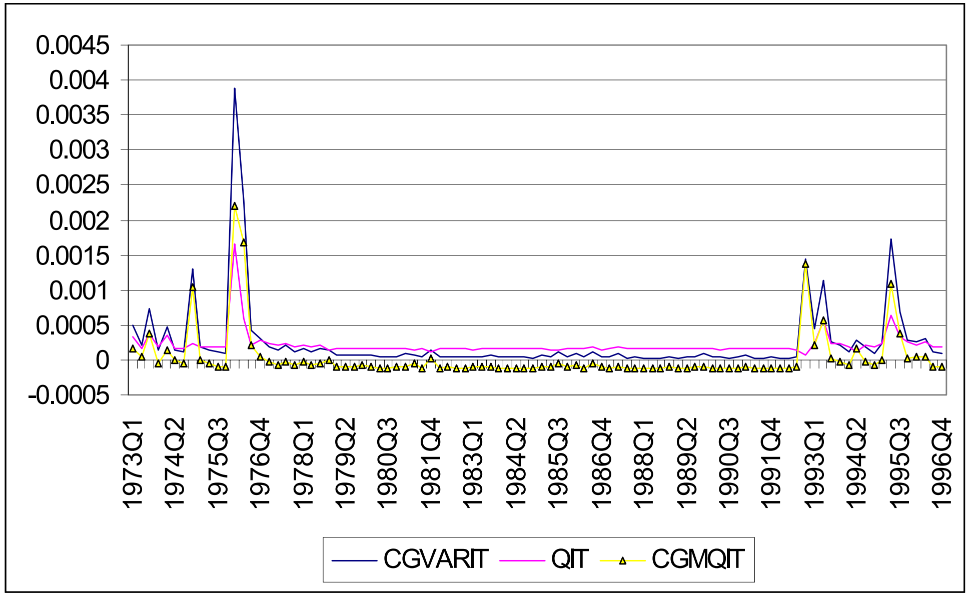
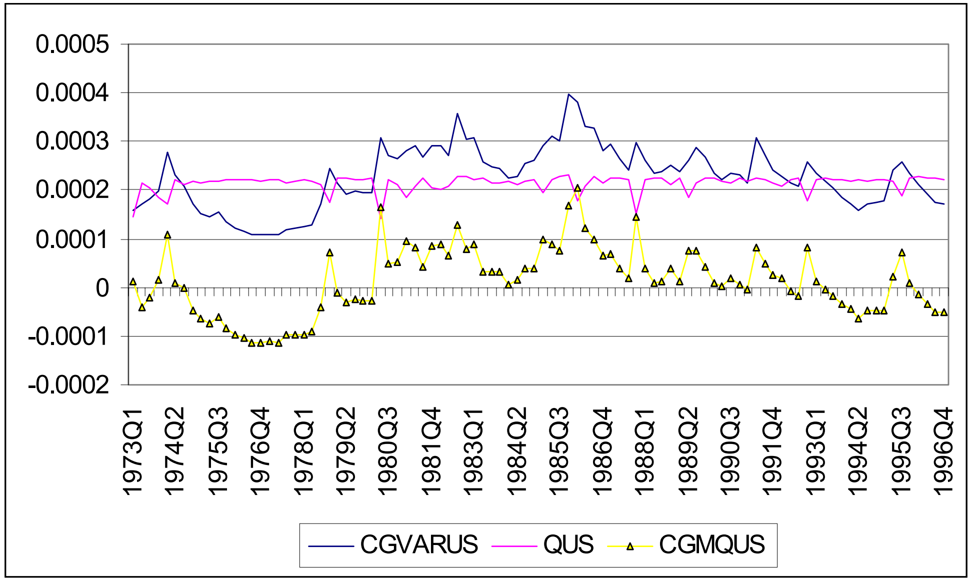
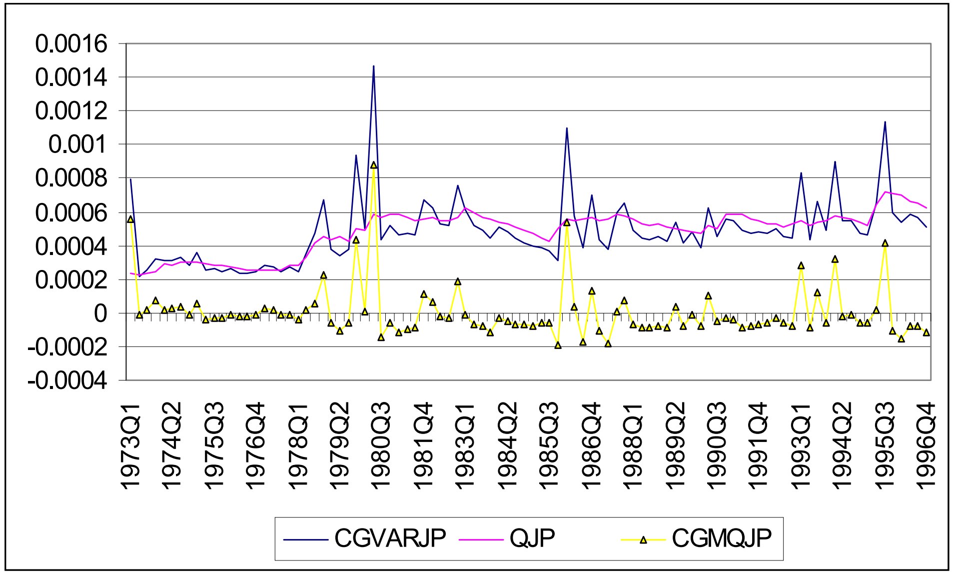


Figure B2: Total (CGVAR), Transitory (CGMQ) and Permanent (Q) component measures of volatility for G7

Key JP: Japan; CA: Canada; US: United States





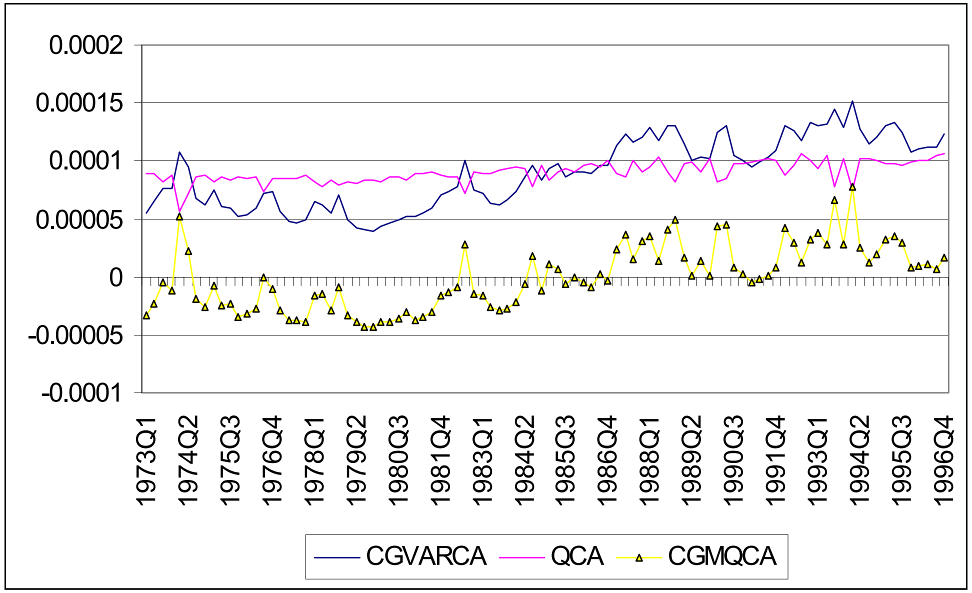
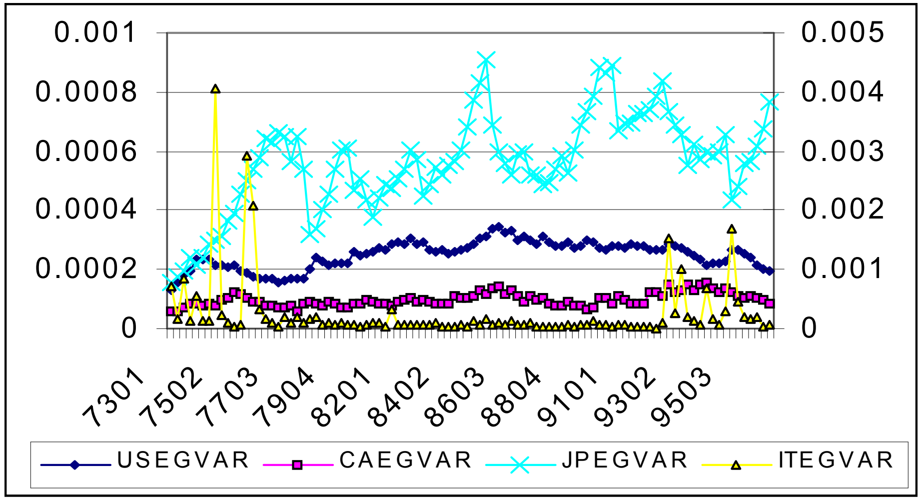
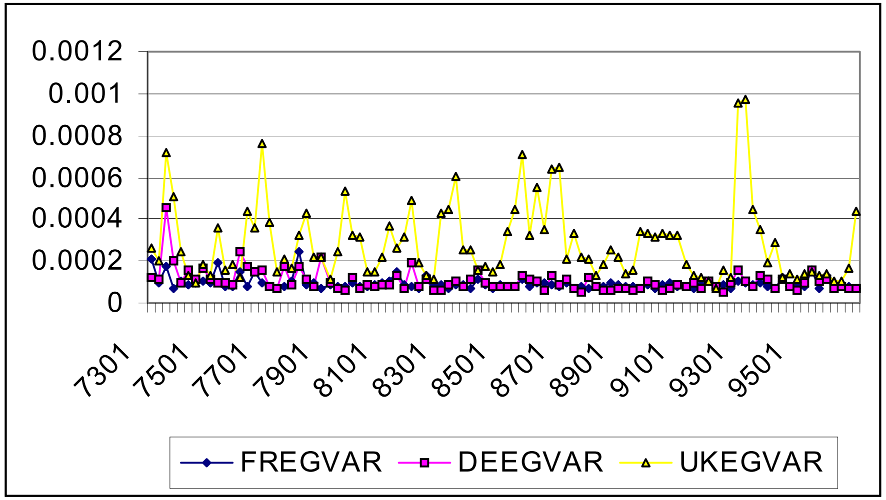


Figure B3. Exponential GARCH conditional volatility





JP: Japan; CA: Canada; US: United States
IT: Italy (second y-axis)

UK: United Kingdom; DE: Germany; FR: France;