Explaining European Short-term Interest Rate Differentials: An Application of Tobin's Portfolio Theory

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ABSTRACT

This paper seeks to identify potential determinants of short interest rate differentials across European countries. We rely on the portfolio theory of Tobin to choose our set of risk factors and then assess the ability of these macroeconomic variables to influence both the conditional mean and volatility of interest rate differentials. The macroeconomic variables employed in the analysis may be loosely considered to reflect both domestic government fiscal and monetary policy and international influences.We find significant ARCH-in-mean effects, implying that the conditional volatility of the interest rate differential exerts an important influence in the determination of its mean value. There are also significant short-run contagion effects whereby volatility in the macroeconomic factors is transmitted to the overall riskiness of the differential which in turn impacts upon the level of the differential.

Keywords: Interest rate differentials, risk premium, multivariate ARCH.

JEL Classification: F3,G1

1 Introduction

It is well known that interest rate differentials across countries varies over time, telling us that some factor, or set of factors, is causing this variation. These time-varying differentials are most usually explained in terms of a risk premium attached to the debt instruments of one country above another, either due to economic or political uncertainty (see Frankel & MacArthur (1988), Limosani (2000)). However, until we have a better understanding about the source of the risk premium, attempts to adequately explain its existence and predict its future movements will prove difficult to achieve. Thus far, little attempt has been made in the empirical literature to identify the sources of the uncertainty which gives rise to the observed risk premia. In this paper, we focus on short-term interest rates in a number of European countries and endeavour to explain the differential for each country vis-à-vis Germany. In an earlier paper, Flavin and Limosani (2000) use a statistical model to show that the debt/GDP ratios of European countries helped to explain movements in risk premia vis-à-vis Germany but our goal in this paper is to provide a theoretically well-founded set of factors to use in our analysis. Tobin's work on portfolio selection provides us with such a theoretical foundation for the model by allowing us to identify a set of macroeconomic factors that may potentially explain short-term interest rate differentials.

Portfolio theory implies a risk - return trade-off and therefore investors have to be compensated for holding more risk by earning a higher return on government debt instruments. Asset risk is usually measured in terms of the (conditional) volatility of its return but it is our conjecture that other risk sources may also contribute to the overall riskiness of an asset. Consequently, volatility in the wider economic environment may be transmitted to government bonds. Such contagion effects will cause any potential investor to seek even more compensation in the form of a greater required return. We propose to model the volatility of the asset conditional on our set of macroeconomic variables and assess their impact on the level of the differential as well as determining the influence of each of the variables on the riskiness of the asset. Most of the previous literature has tended to focus on the first moment effects of macroeconomic variables on asset prices, without paying due attention to the potential second-order effects which we find to have a small but significant impact on the determination of the interest rate differential.

Our model is a combination of two econometric techniques. A VAR model is employed in the mean equation with the second-order moments modelled using a (G)ARCH model. This type of model is perfectly suited to capturing risk-return relationships. We estimate the asset risk in a comprehensive multivariate framework and then allow the computed conditional volatility to exert its influence on the level of the differential, thereby using a VAR - Multivariate ARCH-*in-mean* model. This approach allows the macroeconomic variables to have a direct influence in determining the level of the differential and also an indirect impact through their effects on the conditional variances and covariances of the process.

The paper is structured in the following way: the second section provides a sketch of the theoretical framework. The third section contains a description of the empirical model. The fourth section presents and discusses the empirical results while the final section provides some concluding remarks.

2 Theoretical Background

The CAPM and other mean-variance models provide a loose rationale for modelling the demand for a domestic asset as a function of the structure of expected yield (Tobin(1958;1982), Markowitz(1952), Constantidines and Malliaris(1995)).

The demand function for domestic government bonds in real terms can be expressed as:

$$\left(\frac{B^d}{p}\right)_t = f\left[(i-\pi)_t - (i^* - \pi^* - E_t\Delta S_{t+1})_t\,, \left(\frac{Y}{p}\right)_t, \left(\frac{W}{p}\right)_t, \sigma_t^2\right], \qquad (1)$$

where all the variables marked with * refer to the foreign country and $\frac{B^d}{p}$ is the real demand for bonds of a domestic investor, i is the nominal interest rate on the relative asset and π is the inflation rate. The first element within the square bracket represents the real ex-ante excess return of a domestic asset with respect to a foreign asset with similar characteristics. Y is nominal income, taken as an indicator of capital market imperfection; W is financial wealth; σ_t^2 is the conditional variance representing the underlying riskiness of the asset arising from the uncertainty of asset returns.

Expressing the demand for government bonds as a proportion of nominal GDP, equation (1) can be written as:

$$b_t = f\left[(i-\pi)_t - (i^* - \pi^* - E_t\Delta S_{t+1})_t\,, w_t, \sigma_t^2\right], \qquad (2)$$

where the lower case letters, b and w, denote that the corresponding upper case variables have been divided by nominal income.

The supply of government bonds in the economy arises from the need to finance the public deficit and from open market operations by the relevant fiscal authority, with the former being the more dominant factor. The government budget constraint can be written as:

$$G_t - T_t + i_t B_{t-1} = \Delta B_t + \Delta M_t, \qquad (3)$$

where G$_t$ is government expenditure,T$_t$ is government revenue from taxes; B$_t$ is government debt at the end of period, i$_t$ is the interest rate on government debt, typically represented by a long-term bond yield; Deflating equation (3) by nominal GDP (Y) and re-arranging we obtain:

$$d_t + \rho_t b_{t-1} = \Delta b_t, \tag{4}$$

where d$_t$ $= g - \pi + \Delta m - (\pi + \nu)$ is the government primary deficit expressed as proportion of nominal GDP and $\rho_t = i - \pi - \nu$, is the ex-post interest rate adjusted for real output growth, (ν).

The equilibrium condition in the bond market[1] can be written as:

$$f\left[(i-\pi)_t - (i^* - \pi^* - E_t \Delta S_{t+1})_t\,, w_t, \sigma_t^2, b_{t-1}\right] = \Delta b_t. \tag{5}$$

This condition can be interpreted as an implicit function of the form:

$$F\left[(i-\pi)_t - (i^* - \pi^* - E_t \Delta S_{t+1})_t\,, w_t, \sigma_t^2, b_{t-1}, \Delta b_t\right] = 0, \tag{6}$$

which can be solved as:

$$(i - i^*)_t = \varphi\left((\pi_t - \pi^*)_t, E_t \Delta S_{t+1}, w_t, \sigma_t^2, b_{t-1}, \Delta b_t\right). \tag{7}$$

Assuming that the ratio, $\frac{W}{Y} = w$, changes very slowly and that is approximately one, equation (7) expresses a relationship between the equilibrium short term interest rate differential, the debt/GDP ratio, the inflation rate differential and the conditional variance. Assuming that in the steady state position $\Delta b_t = 0$ and π^* is a function of π and $E_t \Delta S_{t+1}$ as suggested by the

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[1] This equilibrium condition should include the demand for domestic bonds by foreign investors. However, it is well known (home bias puzzle), that investors hold little of financial wealth in foreign assets. Consequently, almost all variations in the bond market come from domestic demand.

Purchasing Power Parity (PPP) condition, equation (7) can be expressed only in terms of domestic variables and the exchange rate of the domestic country vis-à-vis the foreign country as follows:

$$(i - i^*)_t = \varphi \left(\pi, E_t \Delta S_{t+1}, b_{t-1}, \sigma_t^2 \right). \tag{8}$$

Equation (8) suggests that equilibrium short-term interest rate differentials depend not only on their own volatility, as expressed by its conditional variance, but also on a set of macroeconomic variables such us the domestic inflation rate, the debt/GDP ratio and the expected rate of depreciation of the exchange rate. The first two variables may be loosely interpreted as monetary and fiscal policy instruments while the exchange rate may be thought of as capturing international effects.

When addressing the question of how we should model the conditional variance, asset pricing models fail to provide a guide as to the sources of time variation in the conditional variance. Tobin(1982) observes:

> Asset demand functions cannot be expected to be stable in the face of significant variations in the economic environment. The variances and covariances of returns on several assets reflect probability distribution of more fundamental shocks to the economy. These are exogenous shocks in technology, tastes and foreign economies as well as in government policies (Tobin, 1982, p.186).

This paper proposes and implements a multivariate ARCH-M model in which the own volatility of the asset price, conditional on a set of observable macroeconomic variables, exerts an influence on the level of the asset price. This approach creates a plausible link between the financial world and the macroeconomy and appears to be most consistent with the intuition expressed by Tobin in his *Nobel Lecture*.

3 The Empirical Analysis

3.1 The Model

It is commonly accepted that the major problem of implementing multivariate (G)ARCH models is that it can be extremely difficult to achieve convergence given the vast number of potential parameters in the conditional variance-covariance matrix. Therefore, it is necessary to put some restrictions on the formulation of these moments.[2] The M-ARCH model of Flavin & Wickens (1998) is adopted to investigate the potential link between short interest rate differentials across european countries and the macroeconomic variables identified in the previous section. This parametrization is a variant of the BEKK model and requires the estimation of the same number of parameters.[3] Its appeal lies in the fact that it allows us to disentangle long-run and short-run sources of risk, thereby giving us much more information on the importance of the contribution of the individual factors. This econometric approach allows the macroeconomic variables to influence both the conditional mean and covariance structure of the short-interest rate differential between each country and Germany, our benchmark country. The M-ARCH structure is ideally suited to this type of analysis as it captures the time variation in the premium while at the same time being consistent with

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[2] For a complete review of this topic and alternative formulations, see Bollerslev, Engle and Nelson (1994).

[3] This parameterisation is consistent with the covariance stationary model developed in Engle and Kroner (1995).

many of the stylised facts of asset prices such as thick tails and volatility clustering.

We estimate a four variable M-ARCH *in-mean* model as follows for each country;

$$\begin{aligned} &\mathbf{x}_t = \boldsymbol{\alpha} + \boldsymbol{\beta}\mathbf{x}_{t-1} + \boldsymbol{\gamma} h1_{t-1} + \boldsymbol{\epsilon}_t \\ &\boldsymbol{\epsilon}_t \mid \Psi_{t-1} \sim N(0, \mathbf{H}_t) \\ &\mathbf{H}_t = \mathbf{V}'\mathbf{V} + \mathbf{A}'(\boldsymbol{\epsilon}_{t-1}\boldsymbol{\epsilon}_{t-1}' - \mathbf{V}'\mathbf{V})\mathbf{A} \end{aligned} \quad . \tag{9}$$

In view of the non-stationarity tests performed, we define the following vector of stationary variables, $x_t = (ShortDiff_t, \Delta exc_t, \Delta \inf lation_t, \Delta Debt/GDP_t)'$.[4] $ShortDiff_{i,t}$ is defined as the time t differential between the short-term interest rate in country i and Germany.[5] In the analysis, Germany is considered to be the benchmark country and is exogenous to the system. Taking Germany as exogenous is justified on two grounds; firstly, it significantly reduces the computational burden associated with the implementation of M-ARCH models and preserves the tractability of the model (treating Germany as exogenous reduces the number of parameters for estimation in the second order moments from 42 to 20); secondly, it seems reasonable to assume that within Europe, Germany acts as a leader country.

Following Flavin & Wickens, we model the conditional mean as a first order VAR system and the conditional covariances as a M-ARCH(1) structure. As equation 9 suggests, the computed conditional variance of the short-term interest rate differential, $h1$, is allowed to influence the conditional mean

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[4] We performed a wide range of unit root tests and then proceeded with stationary variables. Unit root test results are available from the authors upon request.

[5] This exercise is conducted as a partial analysis, trying to assess the importance of the identified macroeconomic variables in determining the interest rate differential. A more complete characterisation of the differential could potentially involve many more variables and the associated difficulties in achieving convergence of the log likelihood function.

equation, making it a M-ARCH(1) *in-mean* model. In the model, $\boldsymbol{\alpha}$ is a $(4 * 1)$ vector of constants, $\boldsymbol{\beta}$ is a $(4 * 4)$ matrix of parameter estimates describing the impact on the mean of the macroeconomic variables, while $\boldsymbol{\gamma}$ is the coefficient on the time-varying risk premium arising from the conditional volatility of the short interest rate differential. In the specification of the second-order moments, the matrix $\mathbf{V}'\mathbf{V}$ captures the long-run covariance structure while the short-run dynamics are captured by the second term on the right hand side of this equation.

3.2 The data

Our data set consists of nominal interest rates on 3 month Eurocurrency deposits on the London market for five countries: Italy, France, Belgium, UK and Germany. Eurocurrency rates were chosen since these "off-shore" rates were free from the effects of capital controls which both France and Italy used in the early years of the ERM. Gros and Thygesen (1998) show that the differential between these rates and domestic (or "on-shore") rates were often close to zero but importantly the differential increased in periods preceeding a realignment. Each country's rate of inflation is based on the consumer price index and the debt represents the outstanding government debt at the end of each period. The exchange rate included in the analysis is the price of 1 DM in the domestic currency. The data sample consists of quarterly data, covering the period from 1978:1 to 1996:4.

4 Results of the Model

The multivariate ARCH-M model was estimated by maximising the log likelihood function

$$LogL = -\frac{nT}{2}\log(2\pi) - \frac{1}{2}\sum_{t}(\log \mid \mathbf{\Omega}_t \mid - \boldsymbol{\epsilon}'_{t+1}\mathbf{\Omega}_t^{-1}\boldsymbol{\epsilon}_{t+1}) \tag{10}$$

recursively using the Berndt, Hall, Hall & Hausmann (BHHH) algorithm where n is the number of assets and T is the number of observations.We report the results in the appendix with corresponding t-statistics in brackets underneath.

4.1 Conditional Mean

As we are primarily concerned with explaining the short interest differential for european countries versus Germany, we concentrate on the first row of the matrices in the conditional mean process. These results fail to offer any support for the macroeconomic variables identified earlier as potentially important determinants of the level of the differential. We find that for all four countries only the first lag of the short interest rate differential contains any explanatory power for the current value of this variable. As well as being statistically significant, these coefficients are quite large, indicating a high degree of persistence in the differential. However, the other macroeconomic variables are insignificantly different from zero which suggests that none of these exert a significant influence on the level of the differential. Risk, as measured by the conditional volatility of the differential, is found to be a statistically significant determinant of the short-run differential especially for France and Italy. The coefficients are small but nevertheless play an important role in explaining the differential, with a 1% increase in the conditional volatility causing the differential to grow by between 2 and 40 basis points. This measure of volatility includes the influences of the variability of the macroeconomic variables considered in the analysis and their covariances with the short interest differential, thereby providing a more suitable measure of the uncertainty inherent in the economic environment. Therefore it can be argued that while the Debt/GDP ratio, the inflation rate and the foreign exchange rate fail to exert a direct impact on the conditional mean process, they still have an indirect effect through their influence on the conditional volatility of the interest rate differential.

Figures 1-4 show the conditional standard deviation computed for each of the countries in the analysis. We see that a pattern emerges. For France and Italy, the risk increases in the period before a major realignment, similar to the finding of Gros and Thygesen (1998) when looking at "off-shore" versus "on-shore" interest rates for these countries. The differential was particularly volatile in the early years of the ERM. Whenever, the currency of these countries came under speculative attack, an increase in perceived risk in interest rates is manifest. This can also be seen for the major currency crisis of the 90's (i.e. Sept 92), though the risk is somewhat dwarfed by the extremely volatile period in the early 1980's. Belgium exhibits more volatility but follows the above pattern. For the UK, the story is a little different. While the pattern looks much the same, the range of movement in the conditional standard deviation demonstrates that the UK / German differential was very much less volatile. Since the UK were not involved in the ERM in the 1980's, it is reasonable to assume that the exchange rate absorbed much of this volatility with interest rates only influenced by contagion effects across neighbouring markets. Even in the aftermath of its entry and subsequent exit from the ERM, the volatility of the differential is lower than the others. Perphas this says something of the markets view of the UK's committment to defend its exchange rate against the D-mark.

Despite concentrating on the interest differential, our results also have important implications for the interest rate parity condition in finance. According to this parity condition, the interest differential should explain the change in the spot exchange rate. However, our results fail to find any support for this hypothesis in any of the countries in the analysis. The β_{21} parameter which should capture this effect is insignificantly different from zero in all the mean equations.

4.2 Conditional Volatility

The first columns of the **V** and **A** matrices capture the effects of the macroeconomic variables on the volatility of the interest rate differential and provide some support for the possibility of these variables exerting an influence in the process determining the interest rate differential. In the long run, the volatility of each of the variables stems mainly from its own past values. This can be seen from the fact the each of the **V** matrices is diagonal. The one exception is in the case of Belgium, where both volatility in the exchange rate and in the debt/GDP ratio exert a significant influence on the volatility of the short interest differential. This is evidenced by the statistical significance of the V_{21} and V_{41} parameters.

While the role of macroeconomic factors is limited to Belgium in influencing the volatility of the short interest differential in the long run, our results are much more supportive of their importance in explaining deviations from the long-run value. It appears that each country's differential vis-à-vis Germany has a long-run level of volatility with temporary deviations from this value arising from volatility spillovers from the macroeconomic factors. We find that for each country at least one of the macroeconomic variables exerts an influence on the volatility of the differential in the short run.

In particular, variability in the exchange rate is an important determinant of short interest differential volatility for both France and Belgium. The inflation innovation appears to be a major source of short-run volatility for each country with the exception of France. However, the debt variable exerts no real impact in determining short-run volatility.

Consequently, we can argue that to varying degrees each of these macroeconomic variables plays a role in determining volatility in the short-term interest rate differential and hence on the risk premium. This fact may have been ignored in the past as their main role is not in determining the level of the differential but rather in explaining its volatility. Therefore these factors exert an indirect impact on the mean process through the lagged conditional volatility variable. It is the case, however, that one or at most two variables are statistically significant for each country and not all three together. This provides some support for using Tobin's portfolio theory to identify the relevant set of variables. This fact may have been ignored in the past as their main role is not in determining the level of the differential but rather in explaining its volatility. Therefore these factors exert an indirect impact on the mean process through the lagged conditional volatility variable.

Our results show that the introduction of a single currency in Europe, we should see short-term interest rate differentials between member countries greatly reduced. This is due to the fact that there will no longer be a foreign exchange rate and inflation will result from a common monetary policy set by a European Central Bank. However, it may still be possible to observe small differentials as fiscal policy will remain under the control of the domestic government and it will be still possible to observe innovations to the debt/GDP ratio. However, it is difficult to envisage member states being able to sustain large differences in Debt/GDP ratios so it is reasonable to expect short interest differentials to be significantly reduced.

5 Concluding remarks

This paper sets out to investigate the causes of short-term interest rate differentials across European countries. Using Tobin's portfolio theory, we identify a set of macroeconomic factors which may potentially explain the differential. These factors are domestic inflation, Debt/GDP ratio and the foreign exchange rate against Germany, our benchmark country. We use a M-ARCH *in-mean* model to allow these macro variables to influence both the conditional mean and conditional second order moments of the process. The findings are mixed, with the macro variables playing a much greater role in the determination of the second order moments but only exerting an indirect influence in the mean generating process. This provides some support for the adoption of Tobin's theory but does not rule out other sets of variables.

We find that only the lagged dependent variable and the computed conditional variance have statistically significant explanatory power over the mean process of the short interest rate differential. The results show that our macroeconomic variables are of limited use in explaining the level of this variable. The macroeconomic factors only have an indirect role to play in the determination of the differential. Their influence is exerted through the conditional variance which contains covariance effects with each of the macro variables. The volatility is seen to be at its peak in periods approaching the major realignments of the early 1980's for all countries, though the conditional volatility for the UK is significantly lower than the others. This suggests that in the case of the UK, it was its exchange rate with Germany that absorbed economic volatility.

Turning our attention to the conditional variance-covariance matrices, we find that the macroeconomic variables have much more success in influencing this process, especially in explaining short-run deviations from the long-run value. The long-run covariance matrices are predominantly diagonal with the exception of Belgium where both the exchange rate and the debt variable significantly contribute to the volatility of the differential. In the short-run, the conditional volatility shows substantial deviations from the unconditional value and these are mainly due to covariances with the macroeconomic factors. The exchange rate is an important determinant of volatility in the short interest differential for both France and Belgium. The change in domestic inflation has a significant covariance with the differential for each country with the exception of France, while the innovation to the debt/GDP ratio exerts a limited influence on the process.

The key feature of our results is that while macroeconomic variables fail to exert a direct influence on the short-term interest rate differential, they can still play an important role through their influences on the conditional volatility of the differential, which is itself a statistically significant determinant of the level of the differential. This relationship is likely to be overlooked by more traditional models which focus solely on the first order moments of the process. Furthermore, from a policy point of view, we would expect that in post-EMU Europe, short interest differentials will be reduced. The influences of exchange rates and inflation will be eradicated and only fiscal policy will remain as an instrument capable of causing differentials to arise. However, this channel is likely to prove limited due to the fact that debt innovations will be curtailed by the need to coordinate economic policy across member countries and by constraints imposed by the Maastricht treaty and the stability pact.

Appendix

United Kingdom

Conditional Mean Estimates

$$\boldsymbol{\alpha} = \begin{bmatrix} 0.16 \\ (0.41) \\ 0.007 \\ (1.45) \\ -1.60 \\ (-1.21) \\ -1.16 \\ (-0.58) \end{bmatrix}, \boldsymbol{\beta} = \begin{bmatrix} 0.86 & 6.26 & 0.04 & -0.05 \\ (9.52) & (0.30) & (1.12) & (-0.39) \\ -0.006 & -0.10 & -0.0002 & -0.0007 \\ (-0.51) & (-0.30) & (-0.28) & (-0.18) \\ 0.22 & 34.8 & -0.59 & 1.06 \\ (0.84) & (0.51) & (-6.21) & (1.98) \\ -0.16 & -0.10 & 0.05 & -0.17 \\ (-0.97) & (-0.02) & (0.92) & (-0.62) \end{bmatrix},$$

$$\boldsymbol{\gamma} = \begin{bmatrix} 0.29 \\ (1.6) \\ 0 \\ \\ 0 \\ \\ 0 \end{bmatrix}$$

Conditional Second Moment Matrices

$$\mathbf{V} = \begin{bmatrix} 1.08 & & & \\ (5.37) & & & \\ 0.002 & 0.01 & & \\ (0.54) & (6.54) & & \\ 0.31 & 1.30 & 3.88 & \\ (0.27) & (1.20) & (4.79) & \\ 0.79 & 0.10 & 0.60 & 1.62 \\ (1.53) & (0.15) & (1.24) & (3.34) \end{bmatrix},$$

$$\mathbf{A} = \begin{bmatrix} 0.17 & & & \\ (1.29) & & & \\ 0.007 & -0.05 & & \\ (0.10) & (-0.07) & & \\ 0.20 & -0.003 & 0.09 & \\ (3.43) & (-0.27) & (0.29) & \\ 0.22 & 0.005 & 0.01 & 0.40 \\ (1.29) & (0.008) & (0.11) & (0.72) \end{bmatrix}$$

France

Conditional Mean Estimates

$$\boldsymbol{\alpha} = \begin{bmatrix} 0.66 \\ (2.13) \\ -0.001 \\ (-0.17) \\ -0.37 \\ (-0.84) \\ 0.50 \\ (0.65) \end{bmatrix}, \boldsymbol{\beta} = \begin{bmatrix} 0.62 & 4.13 & -0.13 & 0.80 \\ (5.92) & (0.42) & (-0.90) & (1.42) \\ 0.003 & 0.18 & 0.003 & -0.003 \\ (1.39) & (0.95) & (0.66) & (-0.15) \\ 0.08 & -9.04 & -0.30 & 1.20 \\ (0.75) & (-1.48) & (-1.69) & (1.26) \\ 0.03 & -1.04 & -0.02 & 0.07 \\ (0.79) & (-0.59) & (-0.69) & (0.29) \end{bmatrix},$$

$$\boldsymbol{\gamma} = \begin{bmatrix} 0.06 \\ (1.93) \\ 0 \\ \\ 0 \\ \\ 0 \end{bmatrix}$$

Conditional Second Moment Matrices

$$\mathbf{V} = \begin{bmatrix} 6.11 & & & \\ (0.18) & & & \\ 0.04 & 0.04 & & \\ (0.15) & (5.53) & & \\ 0.67 & 0.23 & 1.70 & \\ (0.12) & (0.39) & (6.10) & \\ 0.19 & 0.04 & 0.0007 & 0.37 \\ (0.17) & (0.49) & (0.008) & (5.99) \end{bmatrix},$$

$$\mathbf{A} = \begin{bmatrix} 0.95 & & & \\ (4.16) & & & \\ -0.01 & -0.35 & & \\ (-2.44) & (-1.15) & & \\ 0.15 & 0.005 & 0.09 & \\ (1.01) & (0.93) & (0.28) & \\ 0.05 & 0.01 & 0.10 & 0.03 \\ (1.15) & (0.35) & (1.78) & (0.13) \end{bmatrix}$$

Italy

Conditional Mean Estimates

$$\boldsymbol{\alpha} = \begin{bmatrix} 0.50 \\ (0.94) \\ 0.42 \\ (0.02) \\ 0.75 \\ (0.87) \\ -0.26 \\ (-0.12) \end{bmatrix}, \boldsymbol{\beta} = \begin{bmatrix} 0.81 & 0.001 & 0.02 & 0.11 \\ (13.64) & (0.09) & (0.17) & (0.35) \\ 0.21 & 0.22 & -0.008 & 3.04 \\ (0.08) & (0.86) & (-0.002) & (0.35) \\ -0.15 & 0.01 & -0.26 & 0.45 \\ (-1.53) & (0.36) & (-1.93) & (1.35) \\ 0.03 & 0.01 & 0.01 & 0.01 \\ (0.27) & (0.82) & (0.52) & (0.05) \end{bmatrix},$$

$$\boldsymbol{\gamma} = \begin{bmatrix} 0.02 \\ (2.52) \\ 0 \\ \\ 0 \\ \\ 0 \end{bmatrix}$$

Conditional Second Moment Matrices

$$\mathbf{V} = \begin{bmatrix} 5.74 & & & \\ (1.23) & & & \\ 3.69 & 32.05 & & \\ (0.12) & (4.45) & & \\ -1.93 & 0.16 & 2.80 & \\ (-0.1) & (0.14) & (5.38) & \\ -0.59 & 0.27 & 0.11 & 1.19 \\ (-0.09) & (0.63) & (0.41) & (4.56) \end{bmatrix}$$

$$\mathbf{A} = \begin{bmatrix} 0.80 & & & \\ (4.36) & & & \\ -0.006 & 0.41 & & \\ (-0.64) & (1.32) & & \\ -0.44 & 0.007 & 0.21 & \\ (-3.56) & (0.09) & (1.41) & \\ -0.12 & 0.01 & 0.04 & 0.13 \\ (-0.84) & (0.61) & (0.36) & (0.39) \end{bmatrix}$$

Belgium

Conditional Mean Estimates

$$\boldsymbol{\alpha} = \begin{bmatrix} -0.80 \\ (-1.24) \\ 0.04 \\ (1.69) \\ -0.09 \\ (-0.20) \\ 1.49 \\ (1.43) \end{bmatrix}, \boldsymbol{\beta} = \begin{bmatrix} 0.89 & -0.62 & -0.14 & 0.02 \\ (12.30) & (-0.82) & (-1.29) & (0.22) \\ -0.01 & 0.06 & -0.001 & -0.01 \\ (-1.20) & (0.57) & (-0.07) & (-0.77) \\ -0.06 & -0.49 & -0.57 & -0.02 \\ (-0.64) & (-0.55) & (-4.97) & (-0.19) \\ 0.10 & -0.39 & -0.001 & -0.15 \\ (0.86) & (-0.52) & (-1.03) & (-1.20) \end{bmatrix},$$

$$\boldsymbol{\gamma} = \begin{bmatrix} 0.40 \\ (1.59) \\ 0 \\ \\ 0 \\ \\ 0 \end{bmatrix}$$

Conditional Second Moment Matrices

$$\mathbf{V} = \begin{bmatrix} 1.54 & & & \\ (7.55) & & & \\ 0.17 & 0.40 & & \\ (2.26) & (6.61) & & \\ -0.22 & 0.51 & 1.98 & \\ (-0.52) & (0.98) & (4.64) & \\ -0.83 & 0.19 & 0.19 & 1.91 \\ (-1.90) & (0.41) & (0.45) & (7.06) \end{bmatrix}$$

$$\mathbf{A} = \begin{bmatrix} -0.008 & & & \\ (-0.08) & & & \\ -0.13 & -0.07 & & \\ (-5.97) & (-1.39) & & \\ -0.32 & -0.13 & 0.14 & \\ (-3.47) & (-6.92) & (0.38) & \\ 0.06 & 0.11 & 0.10 & 0.23 \\ (0.47) & (6.34) & (0.53) & (0.98) \end{bmatrix}$$

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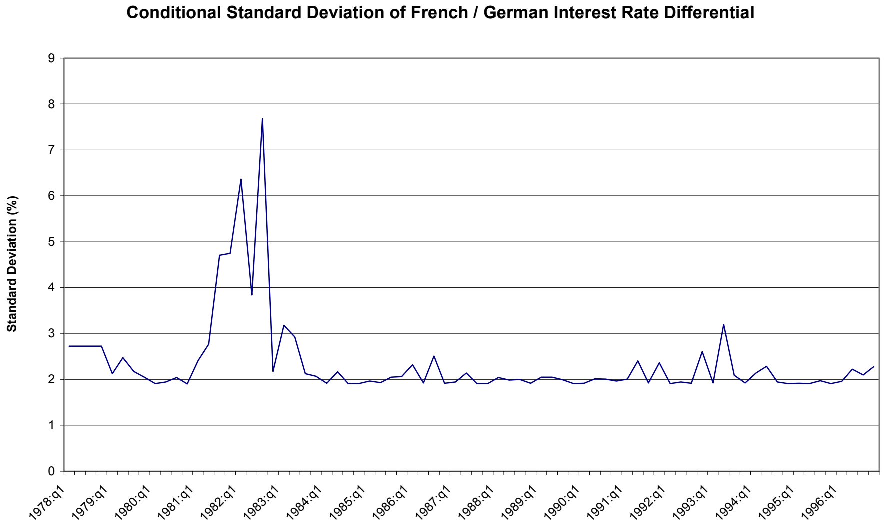

Figure 1:

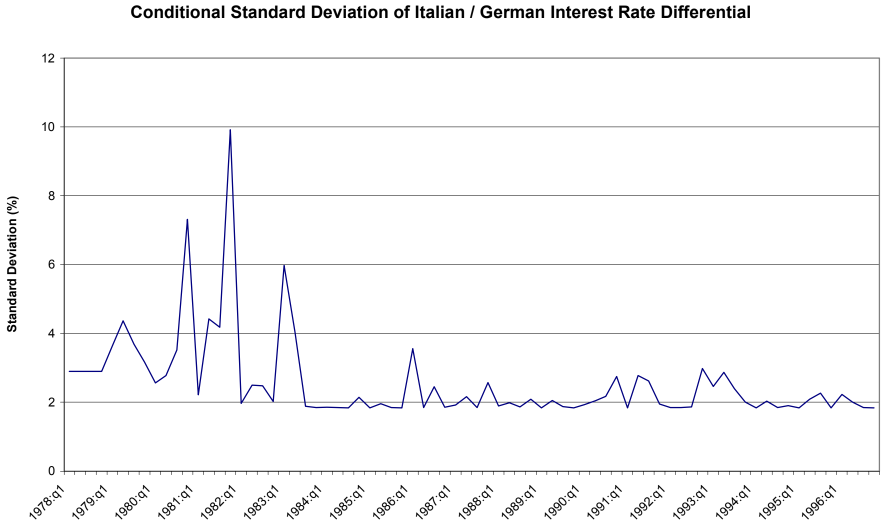

Figure 2:

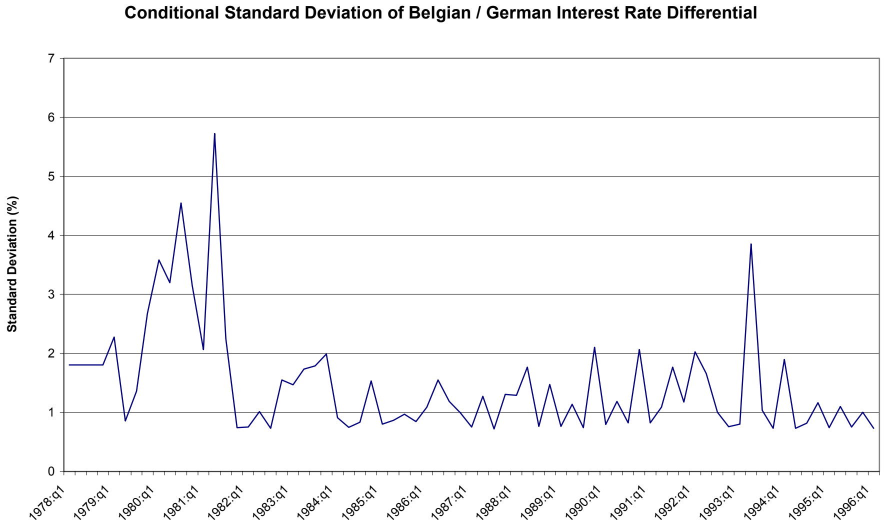
Conditional Standard Deviation of Belgian / German Interest Rate Differential

Figure 3:

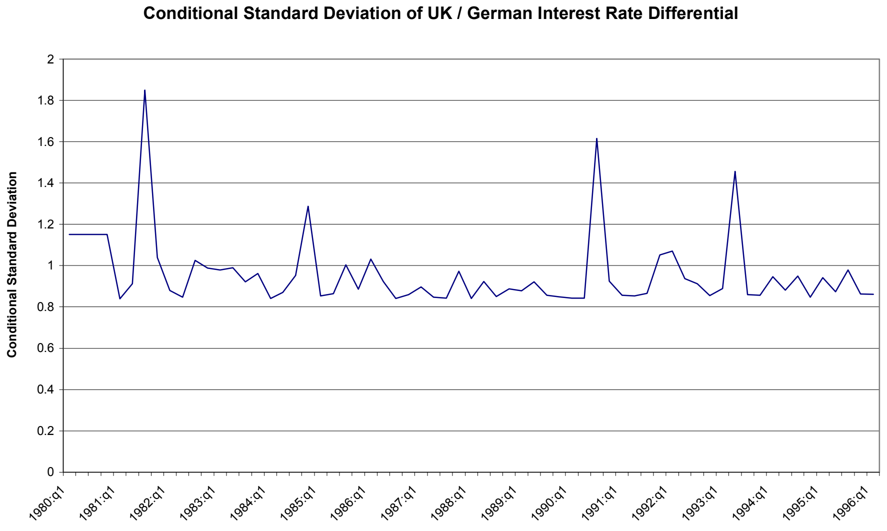
Conditional Standard Deviation of UK / German Interest Rate Differential

Figure 4: