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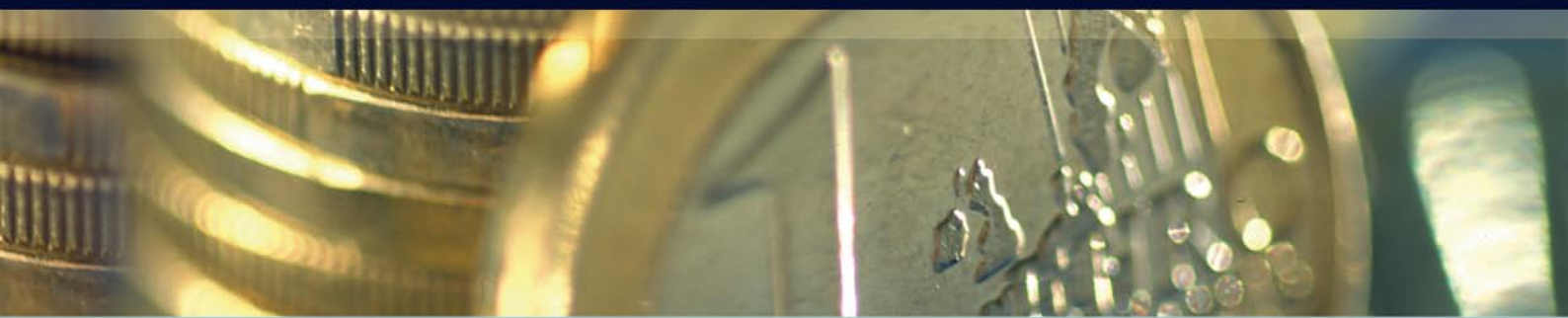
Sovereign bond market integration:
The euro, trading platforms and globalisation

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Sovereign bond market integration: the euro, trading platforms and globalization

Alexander Schulz[*] and Guntram B. Wolff[**]

June 18, 2008[††]

Abstract

We disentangle different driving factors of sovereign bond market integration by studying yield co-movements of EMU countries, the UK, the US and 16 German Länder in the last 15 years. At a low frequency of weeks, bond market integration has increased gradually in the course of the last 15 years in EMU countries, as well as the UK, the US and the German Länder. The euro, as well as increasing international capital flows, appear to drive low frequency integration. In contrast, yield adjustments to changes of the German benchmark bond at high frequencies, i.e., 2 days, remain relatively low until October 2000, when a sharp increase in integration can be observed in all samples. The increase in high frequency integration can be attributed to electronic trading platforms becoming functional. The change-over from national currencies to the euro can not explain the dramatic increase in high frequency integration.

JEL: E42, E44, F33, F37, G15

1 Introduction

Capital markets have broadened and widened significantly in the 1990s and the early parts of this century both on a global scale as well as in Europe. The integration of international capital markets is vital for the efficient allocation of capital, which enhances economic growth and contributes to the sharing of risk on an international, regional as well as sectoral level.[1] Two financial markets can be considered fully integrated if identical assets that are traded on two different markets have identical prices at a time.[2] More specificaly, sovereign bond markets can be regarded as integrated if those bonds that are close substitutes, yield the same expected return and consequently their prices tend to fluctuate together. The advent of the European Economic and Monetary Union (EMU) is regarded as a crucial driving force of European financial integration. The abolition of currency risks with the introduction of the euro together with increased bond standardization are widely seen as the main factors behind increased European bond market integration.

In this paper, we take a closer look at the factors driving bond market integration. Which mechanisms have rendered government bonds in EMU closer substitutes, that has led to the documented increase in co-movements of yields (Baele, Ferrando, Hördahl, Krylova, and Monnet 2004)? What can be attributed to the elimination of exchange rate changes, exchange rate risk, globalization of flows and finally technological improvements in price discovery processes? We do so by comparing the result of euro area countries with two control groups: the US and the UK on the one hand and the German states (Länder) on the other hand. Anglo-saxon bonds reflect the global dimension of bond market integration not directly related to the creation of the euro. The unique data set on the German sub-national government bond market allows to assess integration trends in a long-standing "currency union". Finally, we distinguish low and high frequency adjustments. This allows us to disentangle the influence of fundamental factors, which drive the evolution of yields in the long run, from innovations affecting the short term dynamics of international

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[1]See Levine (2005) for the finance-growth nexus and Sorensen and Yosha (1998) and Yosha, Kakemnli-Ozcan, and Sorenson (2001) for the importance of capital markets in risk sharing.

[2]A further criterion is the equal access to instruments or services, i.e. to bank loans. As this is of minor importance for developed countries' sovereign bond markets, we do not discuss this dimension of integration here.

bond markets. The latter may have significant effects on portfolio allocations and thus can have a substantial impact on financial stability.[3] Furthermore, a more liquid secondary market with faster price discovery will reduce the issuer's cost in the primary market.

The first important finding is that low-frequency bond yield dynamics converged not only in euro area countries but also in the UK, the German states (Länder) and to a somewhat lesser extent in the US. This gradual increase on a low frequency started already in the early to mid 1990s. At around 1999 yields look almost perfectly integrated at a low frequency within the EMU. Exchange rate factors seem to be an important determinant of this convergence. We show that controlling for the exchange rate through swap rate spreads considerably increases integration for EMU countries before the introduction of the euro. Factors beyond the exchange rate surely also contribute to this rise in low frequency integration. In a long term trend, capital markets have become more open, both in industrialized and in developing countries. A major contributing factor is the removal of administrative barriers (Kaminsky and Schmukler (forthcoming), Obstfeld and Taylor (2004)). Deeper capital markets, greater bond standardization as well as larger international capital flows are reflected in low frequency integration within Germany.

Our second major result is that on a high frequency a very different pattern of integration emerges. A strong jump in the co-movement of yields is observed during the year 2000 for the euro area countries. However, similar patterns can also be found in the UK and the US. In contrast, the integration level is almost zero for small German Länder bonds. The pronounced increase at a high frequency can be attributed to technical innovations in bond trading (electronic trading platforms) which promote price transparency and competition while reducing transaction costs. Indeed, breakpoint tests exhibit a strong break for the UK, US as well as the euro area around the date of the introduction of the Eurex-Bonds trading system. In contrast, the German Länder bonds are in general not traded on electronic platforms and therefore not well integrated. For those few Länder bonds that are traded, the integration level is comparable to other euro area sovereign bonds.

Our paper relates to an important literature on bond market integration in

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[3]Noticeably, in the recent financial market's turmoil the rush for save and liquid assets brought the sovereigns' bond market integration to a test.

EMU. Pagano and Thadden (2004) note that euro area sovereign and private bond markets have become more integrated in the wake of monetary unification. They note that governments laid the institutional framework for an integrated market, but that integration was also significantly promoted by the response of financial intermediaries for example in the form of pan-European trading platforms. Baele, Ferrando, Hördahl, Krylova, and Monnet (2004) and several ECB publications (e.g., European Central Bank (2007)) investigate co-movements of sovereign bond yields in EMU with the German benchmark. Using monthly yield data, the authors show that EMU countries' yield changes follow more closely the changes of the benchmark country, Germany, after 1999. Moreover, this literature documents a strong decrease in yield spreads in the run-up to EMU. Barr and Priestley (2004), using a conditional asset pricing model in the spirit of Bekaert and Harvey (1995), find that national sovereign bond markets are partially integrated into the global market, but market idiosyncratic risk remains.[4]

The present paper marries the literature on bond integration with a small but growing literature on electronic trading and its implications for financial systems. Sato and Hawkins (2001) provide an overview of the issues. The literature focuses on equity markets as they were the first to introduce electronic trading beyond the posting of indicative quotes. Grünbichler, Longstaff, and Schwartz (1994) find that screen traded Dax futures lead floor traded Dax stocks by a larger amount than in markets, where spot and futures are both traded on the floor. They argue that this is consistent with the hypothesis that screen trading accelerates the price discovery process. Kempf and Korn (1998) investigate the effect of screen based versus floor based trading systems on different measures of market integration of the Dax future and the the Dax index. They find that integration is higher in electronic screen based systems and argue that this effect is driven by lower market frictions which facilitate arbitrage trading. Regarding fixed income markets, to our knowledge no study so far has investigated the impact of electronic interdealer trading systems on sovereign bond market integration. Gravelle (2002) notes that electronic trading systems have increased centralization in government securities markets allowing dealers to solicit quotes from a number of dealers at one moment on one screen. Cheung, de Jong, and Rindi (2005) study the microstructure of the MTS global market bond trading system. They find that Euro MTS

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[4]In an update to that study, Lamedica and Reno (2007) broadly confirm their findings.

and country MTS markets are, despite their apparent fragmentation, closely connected in terms of liquidity.

Finally, our paper is also related to the literature on sovereign bond spreads in Europe and Germany. This literature documents, on the basis of low frequency data, that sovereign bonds of EMU are still not considered to be perfect substitutes as spreads remain. Imperfect yield correlations can therefore not automatically be ascribed to imperfect bond market integration but also reflect imperfect substitutability.[5] Indeed, recently one has observed a remarkable increase in spreads of EMU countries relative to Germany.[6] Few commentators believe that this increase is a sign of a lowering market integration. In fact, fundamental risk factors are found to matter in EMU (Beber, Brandt, and Kavajecz (2006), Hallerberg and Wolff (forthcoming)) as well as in Germany (Heppke-Falk and Wolff 2008) while the importance of liquidity factors has declined with EMU (Codogno, Favero, and Missale (2003), Pagano and Thadden (2004), Gómez-Puig (2006)). For the pre-EMU period, Favero, Giavazzi, and Spaventa (1997) find that long-run spread movements in Europe are determined by exchange rate factors, while country specific shocks drive short-term cycles.

The remainder of the paper is structured as follows. The next section introduces our approach to measuring integration at high, medium and low frequency and presents the data. Section 3 discusses the results. The last section concludes.

2   Empirical approach

A useful starting point for an investigation of bond market integration is the covered interest parity condition (CIP). It states that two, otherwise equivalent, bonds issued in two different currencies should have the same yield expressed in one currency. Deviations from CIP measured with sovereign bond yields of two countries can be attributed to four points: different default risk of the issuer, different liquidity conditions of the bonds, different characteristics of the bonds and finally imperfect market integration preventing or slowing

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[5]This point was already made by Bekaert and Harvey (1995) in the context of international bond market integration.

[6]"Trichet warning over bond spreads in Europe" Financial Times, March 6, 2008.

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arbitrage trading to eliminate yield differences. More formally, in logarithms,

$$i_{j,t,T} = i_{g,t,T} + log(1 + d_t) + f_T - s_t + \varepsilon_t \qquad (1)$$

the interest rate i of country j's bond at time t with maturity T should be equivalent to the benchmark bond of country g plus a term reflecting relative default and liquidity risk $log(1 + d_t)$, plus the appreciation/depreciation of the currency as contracted in forwards, $f_T - s_t$, plus a residual term, which would be a sign of imperfect integration due to broadly defined transaction costs.

In the absence of exchange rate variation and constant relative risks an innovation in the interest rate of the benchmark country should be fully reflected in the yield of the other country's bond if the markets are fully integrated. In other words, yields should perfectly co-move. We test for co-movement of the yields by performing forward looking rolling window regressions of yields of EMU countries, the US, UK and the German Länder on the yield of the German central government bond, the Bund. The rolling-window technique allows to plot the evolution of the integration measure since the beginning of our sample.

Integration levels can be different at different time horizons. For example, it is more likely that large and persistent yield innovations get incorporated into other yields at a long horizon, whereas it is possible that short-term innovations cannot immediately be reflected into yields due to transaction cost, information problems and the like. To capture the notion that yields might adjust at different speeds, we proceed in two steps.

In a first step, we use the linear band-pass filter of Baxter and King (1999) to extract different frequencies of the data. We define three different frequencies: A high frequency equivalent to 2-3 days, a medium one of 3-10 days and a low frequency of 10-30 days. The band pass filter is an ideal filter in that it extracts only the specified frequencies.[7] Moreover, the filter delivers stationary series if the order of integration of the original series is two or less.[8] We can think of the high frequency series as a series of very short run shocks that do not determine the behavior of yields beyond 3 days. Low frequencies, in turn, capture long run movements of yields in the course of a month.

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[7]The filter is in fact constructed by minimizing the distance of the frequency response function and the ideal frequency response function. Visual inspection of actual vs ideal showed a good fit in all cases.

[8]We tested for unit roots and could not find an order of integration higher than two.

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In a second step, we use the filtered series to perform a rolling window regression. More precisely, we estimate:

$$i_{jt}^f = \alpha_{jt} + \beta_{jt} i_{gt}^f + \varepsilon_{jt} \tag{2}$$

where i_{jt}^f is the filtered yield of country j at time t and i_{gt}^f is the filtered series of the German Bund. The regressions are performed on a forward looking window of 500 days which is shifted forward by 10 days. This results in a time series for the estimated coefficients.

If the bond markets are perfectly integrated, we would expect β to be one. Thanks to the extraction of the different frequencies, we can assess the evolution of integration levels in the short, medium and long term. Perfect high frequency integration would imply that any short run innovation to the benchmark yield is reflected in the yield of the respectively compared country on the same or subsequent day. In perfectly integrated markets, we expect integration to be perfect in all frequencies, i.e., any movement of the Bund yield is also visible in the yield of country j.

High frequency integration presupposes a sufficiently high degree of information transparency and operational capacities available to market participants. Adjusting the relative prices of government bonds requires a bilateral price discovery process. Hence, the simultaneous availability of binding quotes is a crucial device for high frequency integration.[9]

At a lower frequency, in turn, market participants can more easily incorporate information, resulting in a higher level of integration. Long run movements of prices can be measured more easily on a low frequency and be priced accordingly. Long term convergence towards the single European currency should be reflected primarily in low frequency yields. The elimination of exchange rates through the euro should lead to an increase of the integration level. This can be achieved already years before the actual introduction of the euro, when markets formed beliefs about participants and conversion rates. Overall, we therefore expect β to be higher at a low frequency as compared to a high frequency. Moreover, we expect technological advances to have a strong impact on high frequency integration, while they should be of less relevance to low frequency integration.

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[9]Indicative quotes or historic transaction prices can only give an orientation about the fair market price and determining the correct instantaneous price, e.g. requesting quotes from dealers by telephone, is time consuming.

A deviation of β from one can be due to imperfect integration but also to the fact that liquidity conditions, default rates and exchange rates are related to the yield of the benchmark bond. It is therefore important, to control for these factors. To control for the influence of varying exchange rates, we repeat the above exercises with yields adjusted by the interest rate swap spread between the currency in question and the German swap rate.[10] In principle the swap adjusted data incorporate exchange rate changes as contracted in forward rate agreements. However, premia for the volatility of interest and exchange rates as well as for credit risk persist. Therefore, even swap adjusted data could show an increase in integration with the introduction of the euro.

Exchange rate volatility might play a smaller role at a low frequency, compared to higher frequencies, since short term variations are likely to cancel out over a certain period. Risk premia for time varying volatility are thus less important, especially in the European ERM system of the 1990s, which defined tolerance bands for exchange rate fluctuations. Therefore, swap rate adjustments, which do not adjust for volatility risk but capture long-run exchange rate evolutions, lead to higher measures of low frequency integration. In turn, for high frequency integration, they are less suited since they cannot capture short term volatility variations which drive a wedge between yields.

Moreover, we present robustness checks to capture time-varying liquidity risks. To do so, we include the bid-ask spread as an additional explanatory variable in the regression. With increasing liquidity risk, we expect the yield of the respective country to go up. Unless liquidity risk is orthogonal to the benchmark yield, the estimated β coefficient could be affected.

To get a clearer picture of structural breaks in the degree of bond market integration, we perform the Quandt-Andrews breakpoint test to test for changes in the coefficient β. This test is basically a rolling Chow (1960) breakpoint test (Andrews (1993) and Andrews and Ploberger (1994)). The basic test statistic is an F-value, which is computed as a normalized difference between the constraint residual sum of squares and the unconstraint residual sums of squares of the two sub-samples. A high F-value therefore indicates a strong structural break.

Our data sample covers the period from 1992 to 2007. We use standard

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[10]See equation B-6 in the appendix for a formal derivation. Within EMU no swap adjustment are necessary.

benchmark bond yields for EMU countries, the UK and US with approximately ten years to maturity at a daily frequency.[11] The yields are computed from daily averages of the respective benchmark bond's price. For the exchange rate adjustment, we use standard interest rate swap rate spreads for a ten year horizon. All these data are taken from Thomson Financial Datastream. To control for liquidity, we use outstanding volume and suitable bid/ask-spreads, both from Bloomberg. With respect to the German Länder, we revert to the data-set of Schulz and Wolff (2008), which comprises master data of all bonds issued by the Länder since 1992. Single bonds' yields as well as the yields of matching Bunds are taken from Thomson Financial Datastream.

3 Results

3.1 Main findings

Figure 1 shows the evolution of the average integration coefficient β from equation (2) for the EMU countries. As can be seen, at a low frequency, the average
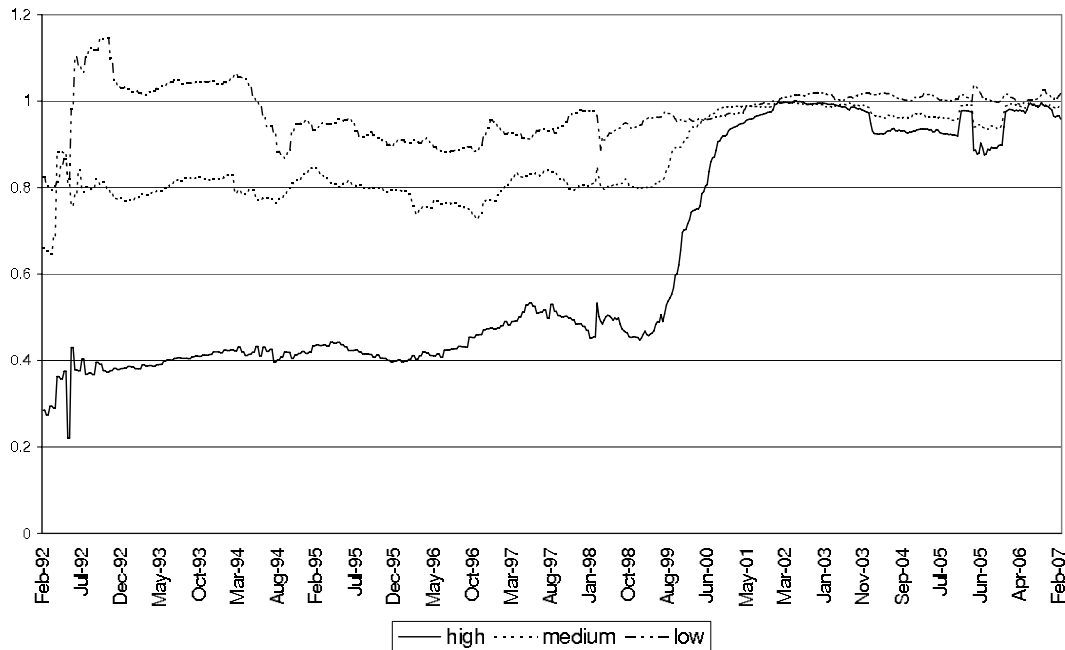
Figure 1: Evolution of average βs of EMU countries, estimated on a 500 day forward looking rolling window. Source: Thomson Financial Datastream, own calculations.

[11]We restrict our analysis to the EMU 12. Luxembourg does not have traded debt and is therefore excluded.

correlation of yields of EMU was hovering around the perfect integration level since the early 1990s. In contrast, for medium frequencies, the integration level is around 0.8, increasing only after 1999. The sharpest increase in the integration level can be observed for high frequency data. Here, the average integration level is around 0.5 during the 1990s but increases abruptly as soon as data from late 2000 enter the forward looking estimation window.[12]

Since average EMU data might conceal a significant amount of heterogeneity across EMU countries, we also provide the variance of β coefficients at each point in time (Figure A-4). The heterogeneity across countries is higher at the high frequency than at the low and medium frequencies. The high frequency heterogeneity almost completely vanishes as of 2002. For low frequency data we observe a generally lower level of variance, which is almost zero with the start of EMU. Looking at individual countries, Figure (A-8) shows that in the early to mid 1990s some countries had significantly deviating βs, while as of late 1997 there appears to be complete convergence.[13] At high frequencies (Figure A-10), we observe a strong jump for most of the countries as also found in the average data.

Performing the same exercise with data from the UK relative to Germany yields a remarkably similar picture (Figure 2). Again, low to medium frequency integration levels are high throughout the sample, while high frequency integration increases steeply when data from late 2000 enter the estimation sample.

Finally, we turn to the USA (Figure 3). Here, the picture is similar in the sense that there appears to be a strong increase in the late 1990s. Moreover, we also observe a gradual increase throughout the 1990s at a low and medium frequency integration level.

Overall, the results for all regions, the EMU, UK and the US, show a small increase in the low frequency integration level in the course of the 1990s.[14] In contrast, at a high frequency, integration starts to increase steeply in late 1998, when the first observation of late 2000 enter our forward looking regression window. Hence, high frequency integration only picks up almost two years after

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[12]As the estimation is done on a forward looking window, observations of fall 2000 enter show up in the results as of summer 1999.

[13]With the obvious exemption of Greece, which joined the EMU only in 2001.

[14]We performed the Quandt Andrews unknown breakpoint test for low frequency data. The largest breakpoint is found for most EMU countries well before the introduction of the euro. The statistics are given in Table A-2.
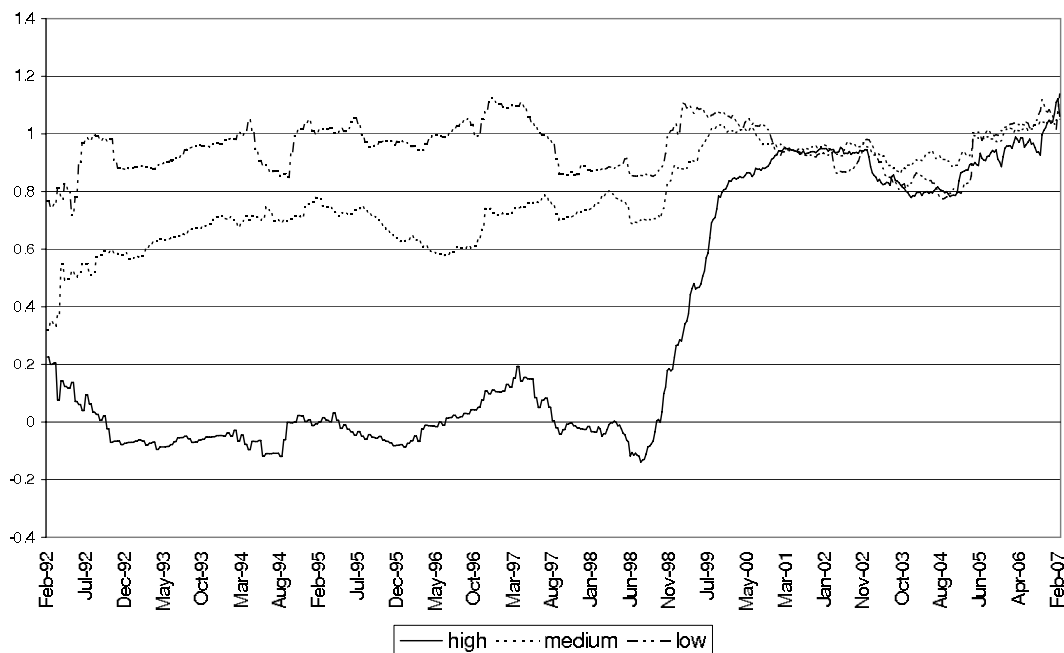
Figure 2: Evolution of β of the UK, estimated on a 500 day forward looking rolling window. Source: Thomson Financial Datastream, own calculations.

the introduction of the common European currency. Moreover, integration with respect to Germany's Bund picks up simultaneously in the UK. With respect to the US, the pattern of increasing integration is similar and can be observed in parallel at low frequencies.

In the high frequency integration, regressions clearly hint at a regime shift in the year 2000. To better capture the exact timing of the jump, we perform a Quandt-Andrews unknown breakpoint test. The test provides an F-statstic for a structural break of the β coefficient in time. The higher the F-value, the greater is the imposed constraint of a model without a break. Figure 4 depicts the F-statistic for the average of EMU countries, the UK and the US. For all three regions, there is a striking peak in the F-statistic around October 2000. Thus high frequency integration jumped at that point in time to a new level. In the EMU as well as in the UK, the integration parameter subsequently is at one. This indicates full integration, i.e., Bund yield innovations are fully mirrored in other government bond yields. The lower level of integration with the US can be attributed to a lack of synchronization in trading hours.

The short interval at which the integration level jumps suggests a change in price discovery mechanisms around October 2000. Traditionally, bonds were traded over the counter, mainly in telephone trades. Even though prices were
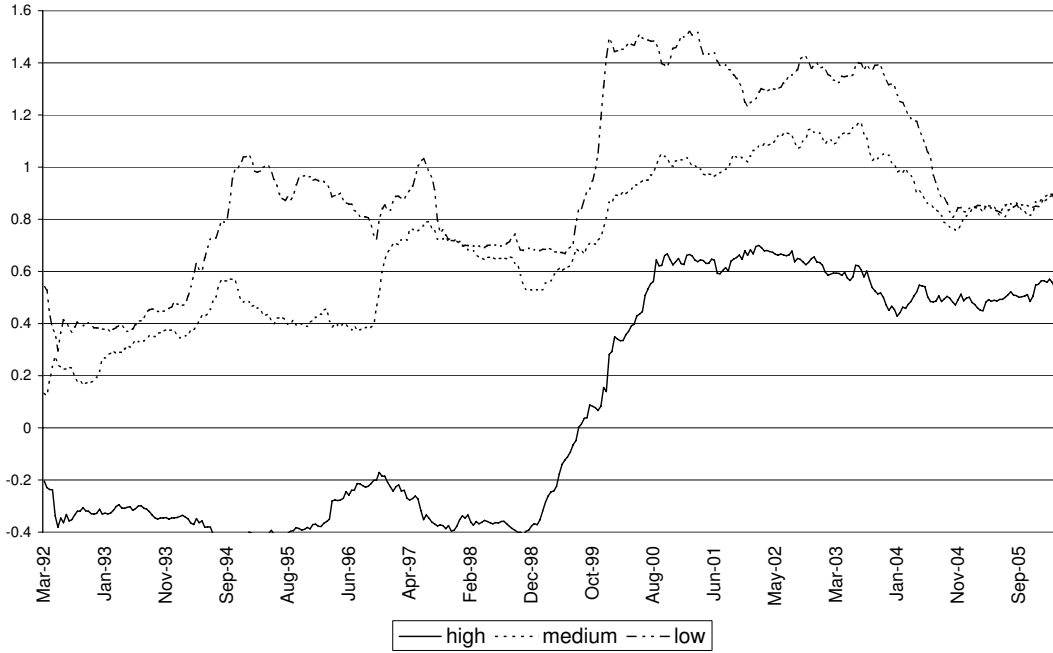
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Figure 3: Evolution of β of the US, estimated on a 500 day forward looking rolling window. Source: Thomson Financial Datastream, own calculations.

posted on electronic information systems like Reuters, they were mainly either indicative quotes or historic prices. Moreover, traders usually did not have access to multiple tradable quotes at one point in time. A potential reason for this jump are electronic trading platforms. In fact, already Hartmann, Maddaloni, and Manganelli (2003, p. 195) suspect that platforms seem to "...have had a significant, positive impact on the integration of government debt markets in the euro area...".

In October 2000, Eurex-Bonds, an electronic bond trading platform in Frankfurt, became functional. It is one of the largest trading platforms for Bunds (Deutsche Bundesbank 2007) and offers real time binding quotes to its members, permitting immediate access to multiple dealers. This increases transparency and thus promotes price discovery, leading to more uniform reactions of government bond yields to innovations. In June 2000 BrokerTec went into operation, which offers a hybrid solution combining voice and electronic trading, which was able to attract trading mainly in US-Treasuries.

Other electronic trading platforms also went into operation around the turn of the millennium. Most notable is the MTS platform, originally created to trade Italian government bonds, which was founded in 1988 and privatized in 1997. In the meantime, MTS has evolved into a trading network. In April
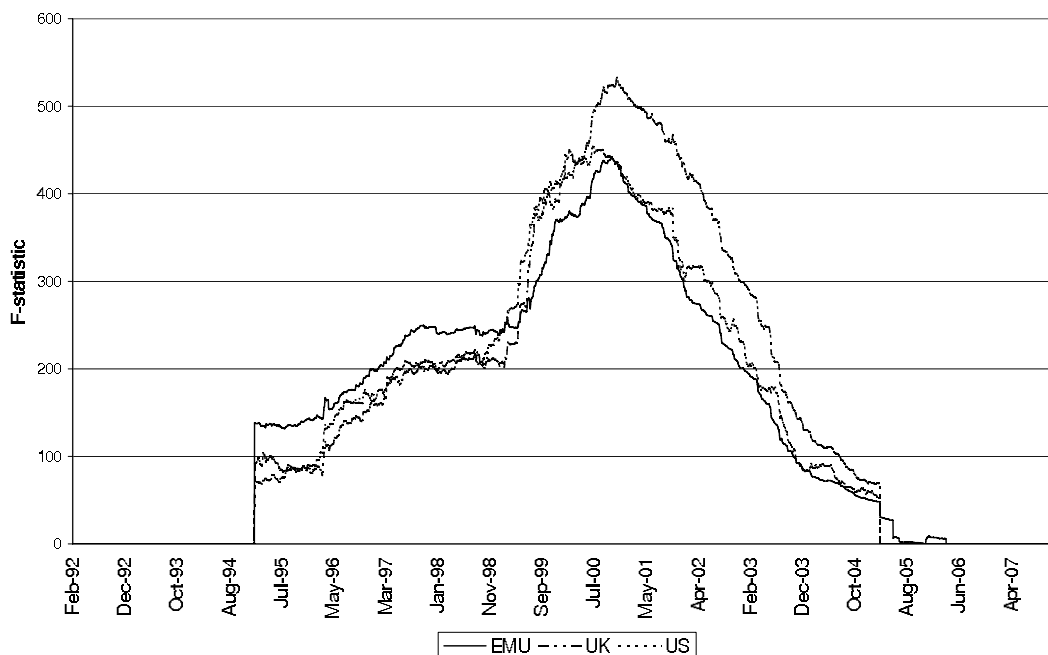
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Figure 4: F-statistic from Quandt-Andrews unknown breakpoint test for EMU, US and UK (high frequency integration).

1999, Euro MTS went into operation, covering European benchmark bonds. However, the MTS system is fragmented, as only the largest and most recent bonds are traded on the Euro MTS platform.[15] To trade the full range of e.g. German bonds, one has to take MTS Germany (launched in April 2001) into consideration. From the perspective of price discovery, inter-dealer systems as MTS and Eurex-Bonds differ significantly from customer related trading platforms like BondVision (part of the MTS group, which started in 2001) or TradeWeb (1998), even though the latter typically record higher turnover.[16] While wholesale markets provide tradable quotes, investors at systems aiming at customers offer prices only at explicit requests. In spite of the success of electronic trading platforms, the majority of trades is still arranged by telephone. In 2006 German federal paper worth more than 18,000 billion euro was traded on the telephone, while more than 400 billion euro worth were exchanged on the different systems of MTS (including the platform BondVision) and the turnover on Eurex-Bonds was slightly above 200 billion euro.[17]

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[15]It appears to be, that the main liquidity is with the national MTS platforms; e.g., a German ten year on the run Bund might not be traded on certain days on Euro MTS. See www.mtsdata.com/content/data/public/ebm/bulletin/.

[16]Recently, investors have pressed to gain a direct access to the inter-dealer MTS systems.

[17]In 2006, less than 2% of trades were executed on stock exchanges (Deutsche Bundesbank (2007), principle of double-counting).

During the 1990s, capital markets and especially bond markets significantly broadened and deepened, globally as well as in Europe. Global issuance activity picked up in the course of the 1990s, peaking in 1999 at a level of 3,355 billion US-Dollar. In the US and both euro area countries and other European countries issuance private sector issues were the main drivers of growth. In the euro area private sector net issues increased from 7 billion US-Dollar (1994) to 120 billion US-Dollar (1999).[18] A major factor for both the growth and the subsequent decline of issuances was the debt-financing of the technology and telecommunication sectors.[19] The German Länder, our control group for bond market integration in a long standing currency union, exhibit a comparable pattern of bond market utilization. Thus, the emergence of electronic trading platforms, which have a significant effect on bond market integration, can be seen in the larger picture of a broadening and deepening global bond market. Furthermore, investors increasingly engaged in foreign securities, which might have provided further support of a more competitive and transparent bond pricing mechanism.[20] Finally, the technological progress of telecommunication has made modern electronic platform feasible in the late 1990s.

All in all, the strong increase in high frequency integration observable in EMU countries as well as the UK and the US around the third quarter of 2000 suggests a change in the speed at which prices are set. This has led to a greater international co-movement of yields. Based on a variety of tests, we attribute this jump to electronic trading platforms that have become functional around that time.

3.2 The role of the exchange rate

To get a deeper understanding of the importance of exchange rate fluctuations for bond market integration, we adjust all yields (except for Germany) by the respective swap spread to Germany.[21] With the thus transformed yield data,

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[18]According to the Bank for International Settlements debt securities database.

[19]Furthermore, European corporations substituted bank loans, the typical form of European debt finance, with direct market debt (Pagano and Thadden 2004).

[20]A major aspect of European cross border investments in the 1990s has certainly been the so called convergence trade prior to the introduction of the euro (Deutsche Bundesbank (2002)).

[21]We use ten year swap rates. In EMU there is only one swap rate, thus no adjustment is necessary in that sub-sample.

we perform the frequency-filtering as for the original series and re-estimate the integration equations.

Figure A-1 - A-3 in the appendix plot the evolution of the estimated βs. Again, we observe a strong increase in high frequency integration, while for low and medium frequency integration, the increase appears to be small and gradual. Hence, the pictures for EMU and UK bond market integration look very similar to the original findings. Exchange rate changes thus do not appear to influence the measured integration. The qualitative evolution for the US is similar, though to a lesser extend. This finding is consistent with Bekaert and Harvey (1995), who cannot reject the hypothesis that integration and exchange rate changes are not connected.

Nevertheless, exchange rate adjustments were a major determinant of spreads pre-EMU. This can be seen by plotting the dispersion of adjusted and non-adjusted yields (see Figure A-6 and Figure A-7). Indeed, adjusted yield differences are only a third of the unadjusted values. Regarding integration, the variance of estimated integration coefficient βs is lower (Figure A-5). Especially at a low frequency, we find that adjustment of yields matters for the dispersion of estimated βs. Figures A-8 and A-9 plot the evolution of the estimated low frequency βs for non-swap adjusted and swap adjusted 10 EMU countries. The range of estimated low frequency βs was roughly between 0.8 and 1.2 for swap adjusted data, while it was between 0.5 and 2.5 without the swap adjustment in the early to mid 1990s. As can be seen, the heterogeneity of estimated βs is much larger in the non-adjusted data, especially in the early parts of the sample. Our finding that exchange rate factors matter for low frequency integration confirms the result of Favero, Giavazzi, and Spaventa (1997). However, even after controlling for exchange rates by swap rates, we observe a convergence in low frequency βs to close to one at around January 1999. This probably reflects the elimination of the exchange rate risk. However, it is worthwhile to notice that the integration level further increases after January 1999, which might reflect advances of the technological possibilities.[22]

All in all, exchange-rate adjustments as measured by swap-rate differences,

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[22]The long-run yield convergence is also reflected in regression B-8's constant α, which measures the average growth difference of yields in the 500 day estimation window. As Figure C-18 shows, in the period of 1992 to 1999, the α for the unadjusted yields is persistently negative at a low frequency, capturing pre EMU yield convergence. In contrast, the constant of the adjusted yields fluctuates around zero.

have an effect on long run yield convergence. For bond market integration as measured by short to medium term yield innovations, swap adjustment play a negligible role.

3.3   German Länder

As an additional control group to the EMU countries, we investigate closely the German Länder. The German Länder faced a common legal framework already in the early 1990s and therefore help to disentangle legal harmonization in EMU countries from other trends. Moreover, the bonds considered were all issued in the same currency at a time, the Deutsche Mark and subsequently the euro.

Figure 5 plots the estimated integration coefficients for the German Länder. High frequency integration levels remain at very low levels throughout the
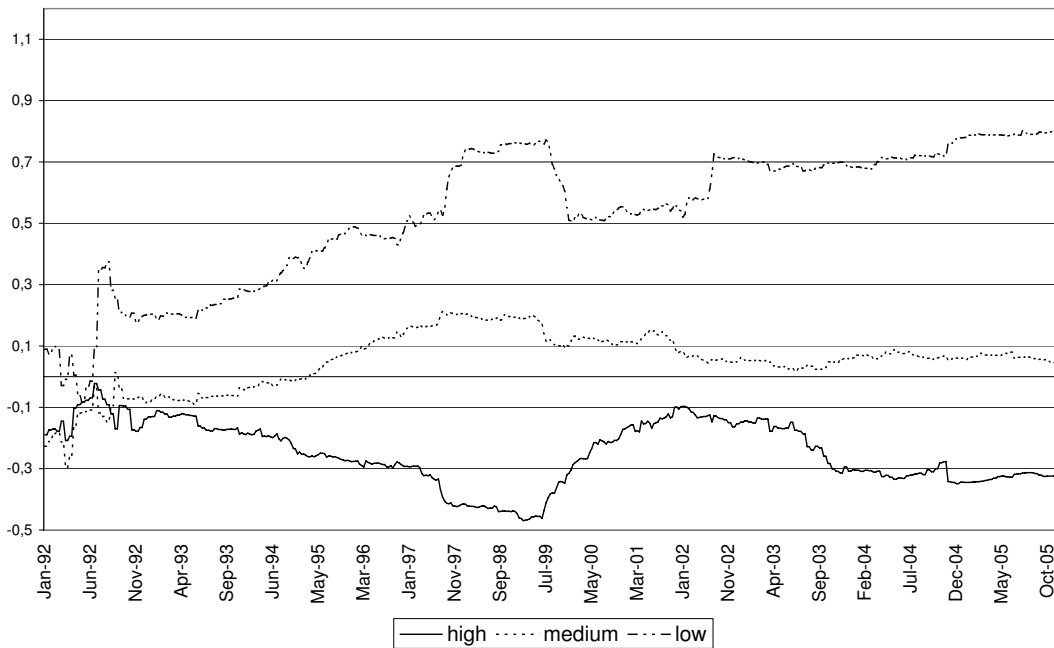
Figure 5: Evolution of average βs of German Länder. Source: Schulz and Wolff (2008), Thomson Financial Datastream, own calculations.

sample. We attribute this low level to the fact that most Länder bonds are quite small in size. This lack of liquidity reduces the incentives to adjust prices relative to the Bund by selling or buying. At a lower frequency, however, we observe a continuous increase in integration levels. This suggests that larger movements of Bund yields are increasingly reflected in Länder yields.

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The increase in low frequency integration mirrors the increase of low frequency integration in EMU. This suggests, as did the increase of the UK integration, that the role of the exchange rate for bond market integration is at best an indirect one. The absence of exchange rates in Germany precludes exchange rate risk as a prime determinant of integration. However, it is possible that through the elimination of the exchange rate of Germany towards the other EMU countries, international investors increased their engagement in the German Länder bond market thereby leading to greater price convergence.

If we look more closely at large bonds, that have the potential to be traded on electronic trading platforms, we find a sample of roughly 40 bonds that exceed the threshold of 1 billion euro, which is required by Eurex-Bonds, only 3 exceed the value of 2 billion euro required by EuroMTS. We pool the data for the bonds between 1 and 2 billion euro and the one for more than 2 billion euro and compare the yield of each individual bond with a comparable benchmark bond of the Bund. Figure 6 plots the evolution of the average β for the two groups. As can be seen, the integration level of the second group with a volume
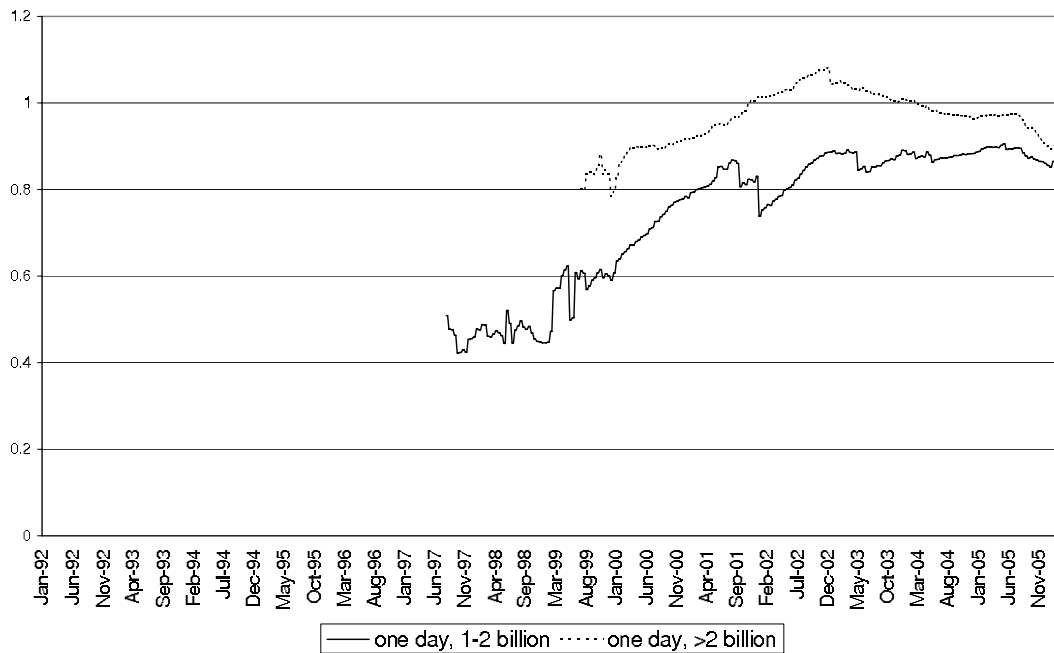
Figure 6: Evolution of average βs of large German Länder bonds. The first large bond was issued in 1996 (''Länder Jumbo). Source: Schulz and Wolff (2008), Thomson Financial Datastream, own calculations.

of more than 2 billion euro each exhibits a higher level of integration. This suggests that liquidity is important for integration. However, we also observe a clear increase in the integration level for the first group as of late 1998, when

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the first observations of late 2000 enter the estimation window. Thus, with the start of Eurex-Bonds, the correlation of yields of the Länder with the federal government bonds has increased from a low of 0.5 to 0.9 in 2003. This again suggests, that a prime motor of high frequency integration is the improvement of technological trading possibilities.

All in all, the German Länder bond market has seen a remarkable increase in integration with the Bund in the course of the last 15 years at a low frequency. At higher frequencies, however, integration levels remain very low. Nevertheless, for large bonds eligible for trading at electronic trading platforms, we can also measure a strong increase in integration levels around the time of the introduction of Eurex-Bonds. The vast majority of German Länder bonds are, however, too small to be traded in electronic platforms; their price discovery process is therefore too slow to show high frequency integration.[23]

3.4 Robustness

We performed a number of robustness checks. To make our results more easily comparable with the paper by Baele, Ferrando, Hördahl, Krylova, and Monnet (2004), we regressed the difference of yields of country j on the difference of the German Bund's yield.[24] We use the first difference of yields (i.e., the day-to-day change) to capture fast adjustment of yields. Medium and low adjustment speeds are captured with 5 and 10 business days differences. Baele, Ferrando, Hördahl, Krylova, and Monnet (2004) use one month differences and thus capture very slow and long-run adjustments.[25] The results of this exercise are presented and discussed in depth in appendix C. The results are very much in line with the previously shown figures of frequency filtered data. We again observe a sharp increase of integration levels in the one day difference estimation around the time of the introduction of trading platforms. For lower frequencies, i.e., five and ten days differences, integration seems to increase gradually in the course of the 1990s.

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[23]In the turmoil since summer 2007 market making in Länder bonds has been abandoned or the minimal required bid-/ask-spread has widened, hampering trade. In consequence, a sample of trades on MTS records practically no trades between September 2007 and May 2008.

[24]In doing so, we abstract from any possible co-integration relationship as do the mentioned authors.

[25]The results for 10 days and 22 business days differences look virtually identical. We therefore do not present 1 month differences.

We use the approach of simple rolling windows OLS regression to control for a variety of other factors that might influence integration. Most importantly, we include the difference of the bid-ask spread in the regressions as a control for time varying liquidity premia. Figure C-10 gives the average evolution of the estimated coefficient on the bid-ask spread, while Figure C-11 provides the estimation results of the integration coefficient after controlling for bid-ask spreads and swap adjustments. As can be seen, the inclusion of the bid-ask spread as a control variable does not alter the main results. Moreover, the effect of bid-ask spreads themselves becomes virtually absent in the mid-late 1990s. This is in line with previous findings in the literature that the role of liquidity measures has become smaller in EMU. Overall, the increase in integration levels with data from late 2000 entering the sample appears to be be very robust.

4   Conclusions

The paper documents a gradual and often substantial increase in low frequency sovereign bond market integration in EMU, the UK, the US and the German Länder since 1992. At low frequencies equivalent to a range between 10 and 30 days, yields now almost perfectly co-move with the Bund in the groups of countries and states considered. The gradual increase can be attributed especially to increased international capital flows and greater standardization of bonds. Moreover, the euro had an impact on low frequency integration. At higher frequencies, especially at frequencies capturing day-to-day changes, integration levels were quite low during the 1990s and increased abruptly at around October 2000 in EMU countries, as well as the US and the UK. We argue that this sudden increase can be best explained by technological improvements in the form of electronic trading platforms. Exchange rates seem to play a negligible role for short term integration measures.

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Appendix

A   Main appendix

A.1   Figures
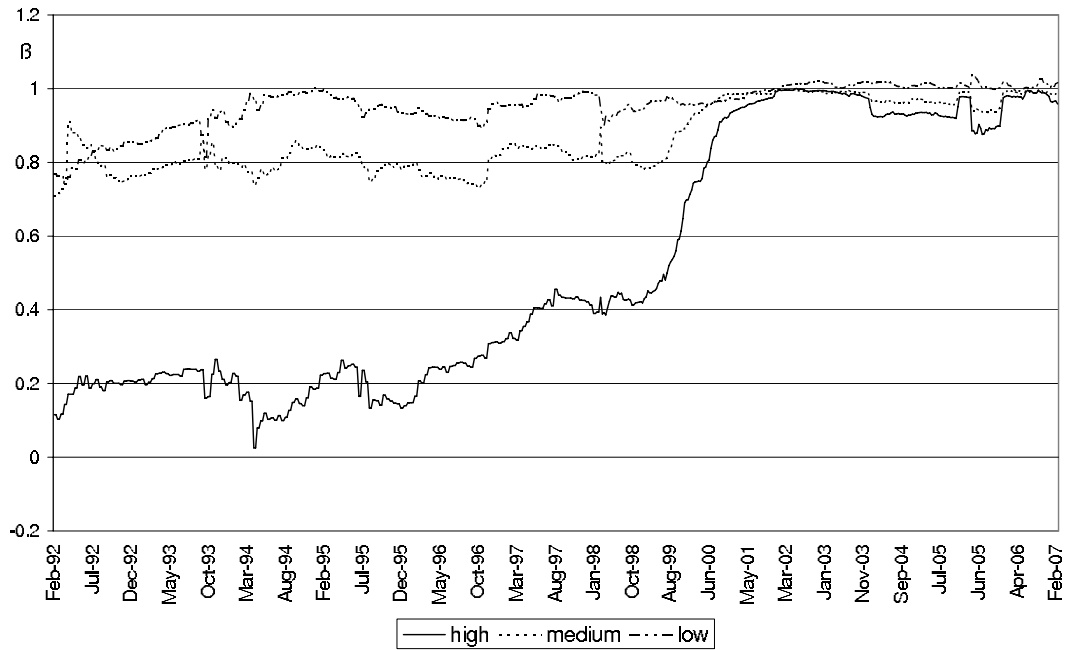
Figure A-1: Evolution of average βs of EMU countries. Yield data are swap adjusted. Source: Thomson Financial Datastream, own calculations.
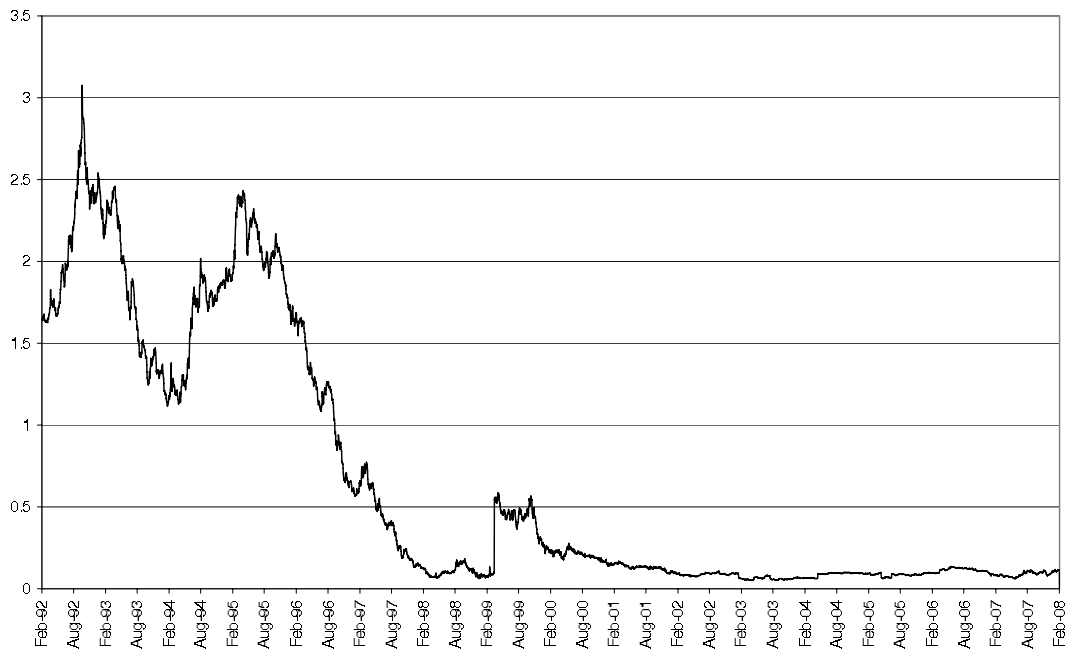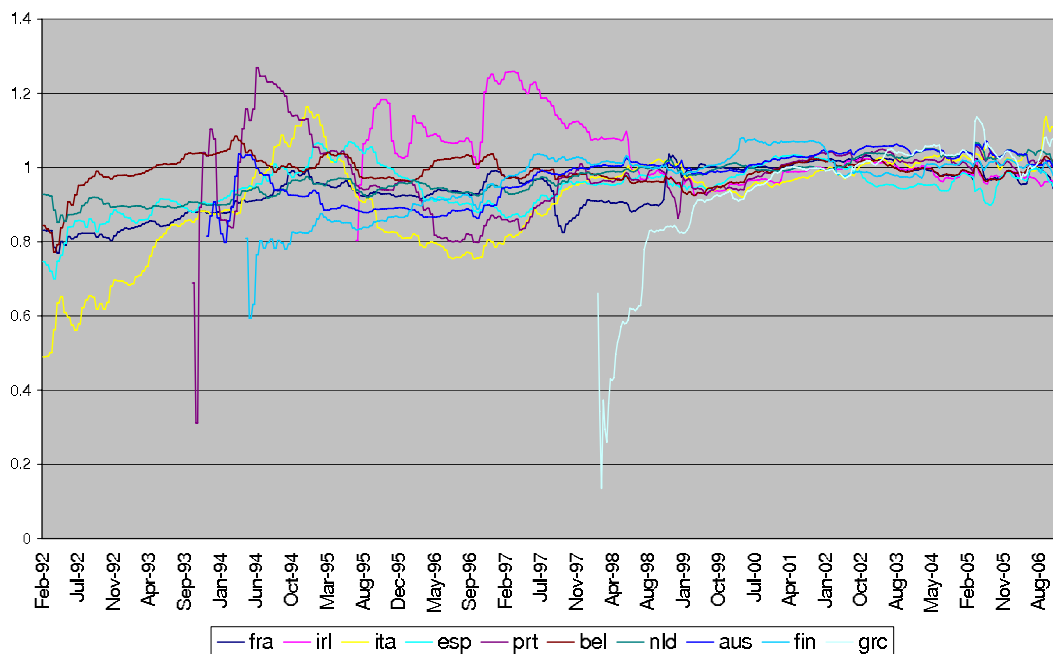
Figure A-2: Evolution of β of the UK. Yield data are swap adjusted. Source: Thomson Financial Datastream, own calculations.
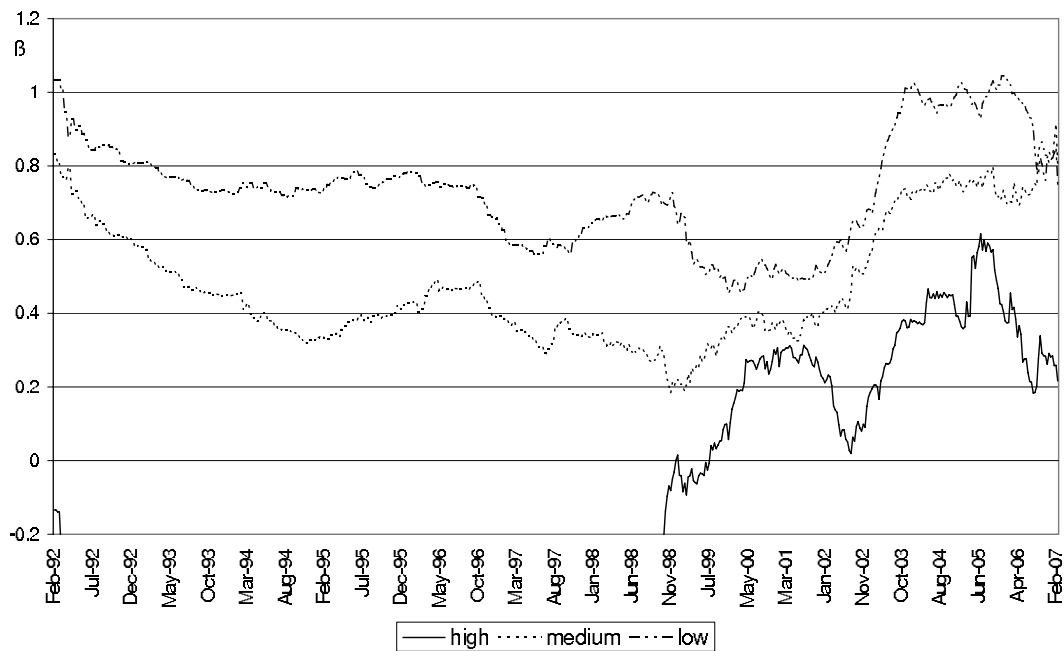
Figure A-3: Evolution of β of the US. Yield data are swap adjusted. Source: Thomson Financial Datastream, own calculations.
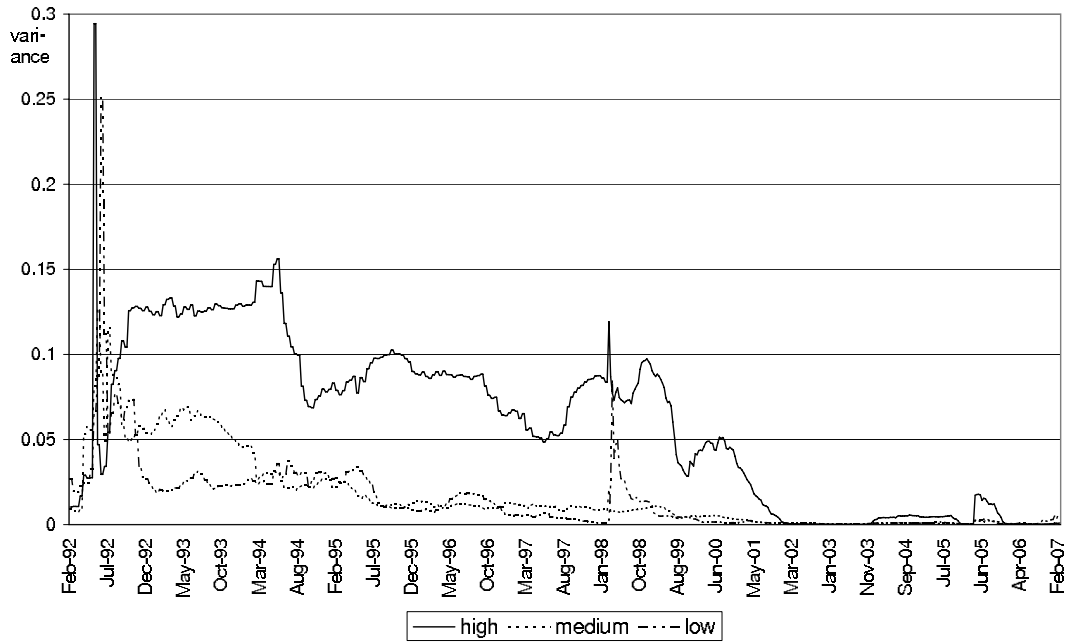
Figure A-4: Evolution of variance of βs of EMU countries. Yield data are **not** swap adjusted. Source: Thomson Financial Datastream, own calculations.
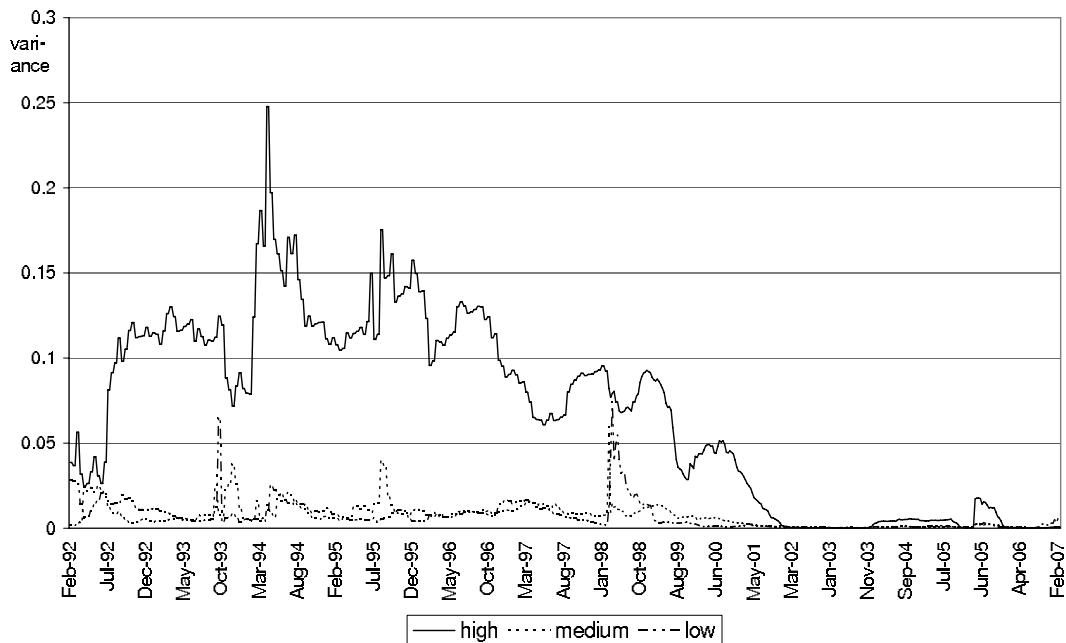
Figure A-5: Evolution of variance of βs of EMU countries. Yield data are swap adjusted. Source: Thomson Financial Datastream, own calculations.

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Figure A-6: Dispersion of yields in EMU. Source: Thomson Financial Datastream, own calculations.
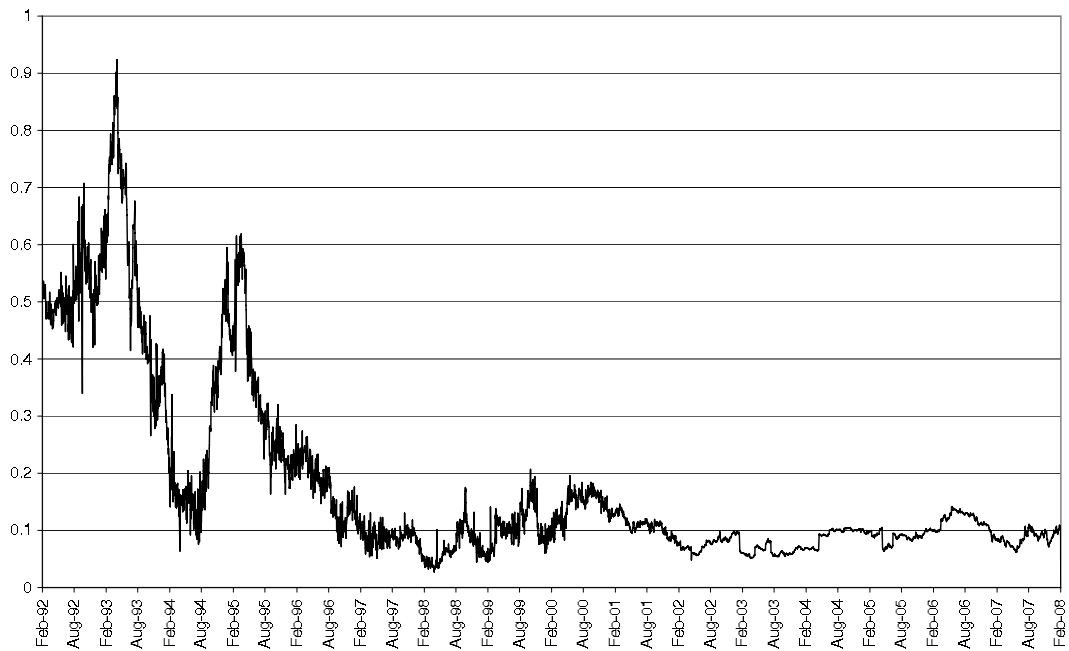
Figure A-7: Dispersion of swap-adjusted yields in EMU. Source: Thomson Financial Datastream, own calculations.

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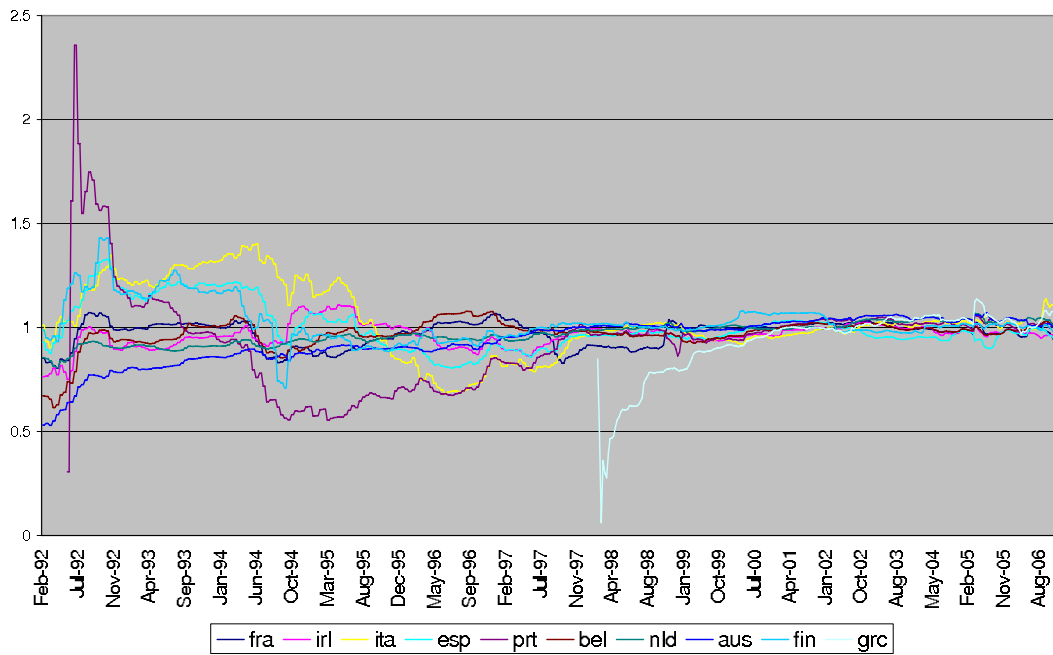
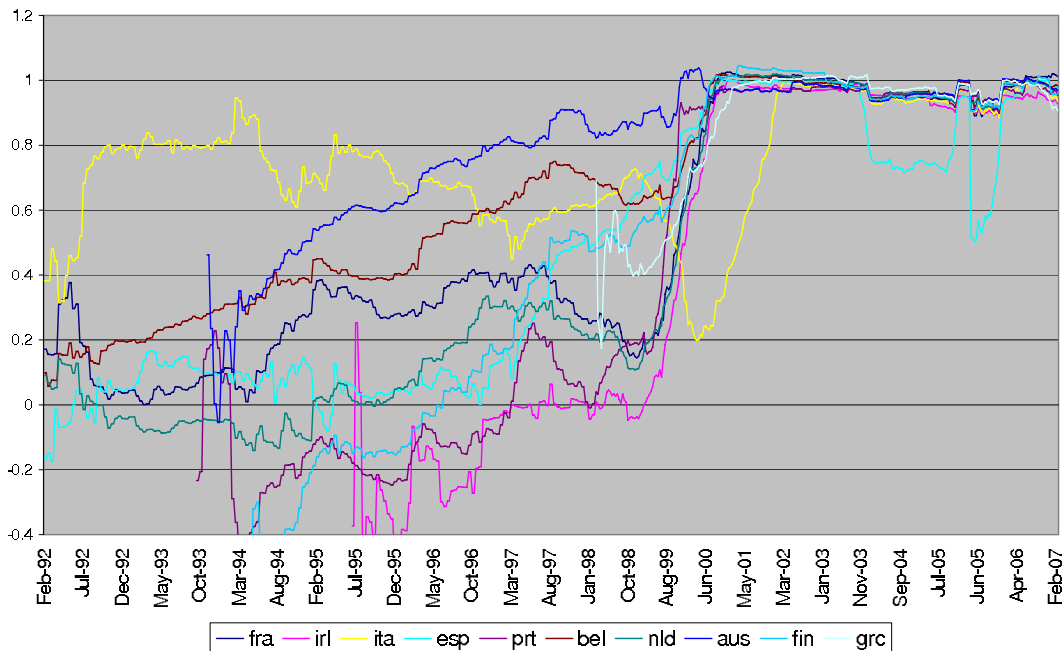Figure A-8: Evolution of β of the EMU at the low frequency. Source: Thomson Financial Datastream, own calculations.

Figure A-9: Evolution of β of the EMU at the low frequency. Yield data are swap adjusted. Source: Thomson Financial Datastream, own calculations.
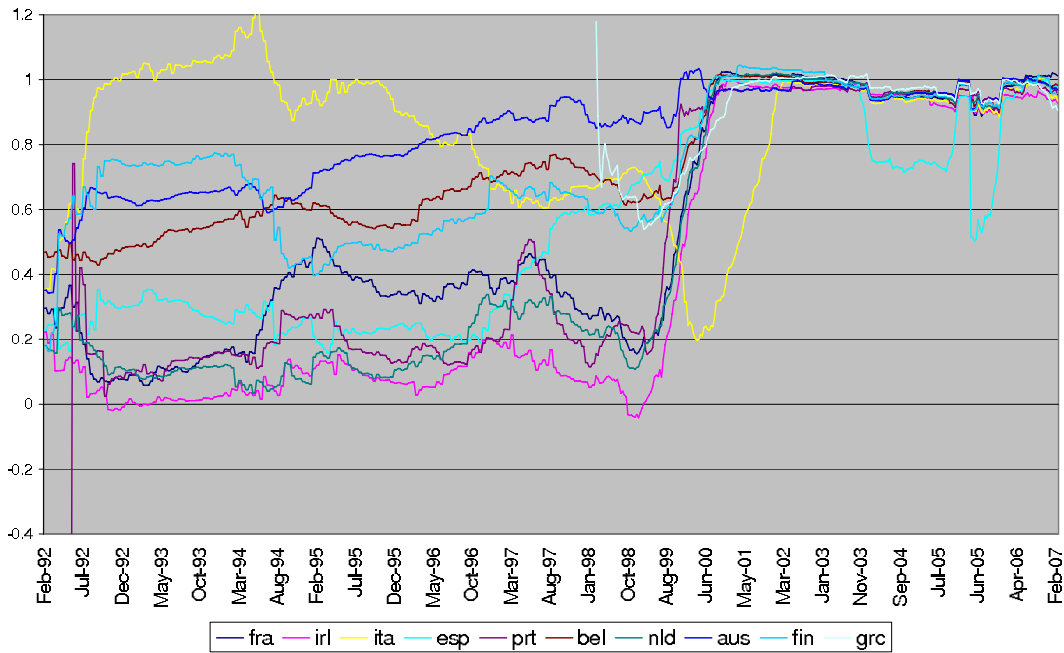
Figure A-10: Evolution of β of the EMU at the high frequency. Source: Thomson Financial Datastream, own calculations.

Figure A-11: Evolution of β of the EMU at the high frequency. Yield data are swap adjusted. Source: Thomson Financial Datastream, own calculations.

Table A-1: Maximum Wald F-statistic with high frequency data

	date	F
aus	5/16/1996	327.9826
bel	9/19/2000	312.6054
esp	11/23/1998	524.2919
fin	9/18/2000	164.1811
fra	10/31/2000	514.4295
grc	3/20/2001	368.1359
irl	12/7/2000	853.7301
ita	4/4/1997	44.67071
nld	9/18/2000	1134.715
prt	12/7/1999	450.4578
uk	12/11/2000	532.8975
us	7/18/2000	455.1495

Notes: Maximal F-value for Quandt-Andrews unknown breakpoint test. Data are not swap adjusted.

Table A-2: Maximum Wald F-statistic with low frequency data

	date	F
aus	9/22/1998	442.40
bel	12/9/1996	24.32
esp	5/2/1996	44.75
fin	6/28/1995	30.49
fra	8/26/1999	26.13
grc	12/10/2001	203.01
irl	3/16/1995	16.81
ita	3/14/1996	82.76
nld	8/2/1999	75.38
prt	9/29/1998	34.60
uk	7/21/2003	10.69
us	1/15/2001	360.01

Notes: Maximal F-value for Quandt-Andrews unknown breakpoint test. Data are not swap adjusted.

B Interest rate parity and bond market integration

A useful starting point for an investigation of international bond market integration is the covered interest parity. The covered interest parity condition states that two risk free assets, i.e., two assets without default and transaction cost risk, should have the same yields adjusted for the expected exchange rate change:

$$(1 + is_{j,t,T}) = (1 + is_{g,t,T}) \left(\frac{F_{t+T}}{S_t} \right)^{\frac{1}{T}} \tag{B-1}$$

where $is_{j,t,T}$ is the spot interest rate at time t with maturity T for country j, and F is the future exchange rate. The benchmark country, Germany, is denoted by g. Suppose the asset of country j has a default probability of p relative to the benchmark Bund, then the arbitrage condition states

$$(1 + i_{j,t,T})(1 - p) + p(1 - \tau)(1 + i_{j,t,T}) = (1 + i_{g,t,T}) \left(\frac{F_{t+T}}{S_t} \right)^{\frac{1}{T}} \tag{B-2}$$

where τ is the fraction of investment lost in case of default. Combining Equation B-1 and B-2, the arbitrage condition can be rewritten as

$$(1 + i_{j,t,T})(1 - \tau p) = (1 + i_{g,t,T}) \frac{(1 + is_{j,t,T})}{(1 + is_{g,t,T})} \tag{B-3}$$

If we define

$$d_{j,t,T} = \frac{\tau p}{1 - \tau p} \tag{B-4}$$

then Equation B-3 can be rewritten as

$$\frac{(1 + i_{j,t,T})}{(1 + i_{g,t,T})} = (1 + d_{j,t,T}) \frac{(1 + is_{j,t,T})}{(1 + is_{g,t,T})} \tag{B-5}$$

Taking logs of B-5 gives approximately

$$i_{j,t,T} = i_{g,t,T} + log(1 + d_{j,t,T}) + is_{j,t,T} - is_{g,t,T} \tag{B-6}$$

Thus, in the absence of exchange rates and transaction and default costs, interest rates of sovereign bonds of country j should equal the interest rates of sovereign bonds of the benchmark country g. To avoid spurious correlation problems (Granger and Newbold 1974) related to (near) unit roots of interest rates, one can estimate the following equation in first differences:

$$\Delta i_{j,t,T} = \alpha_{jt} + \beta_{jt} \Delta i_{g,t,T} + \varepsilon_{jt}. \tag{B-7}$$

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This is a commonly used indicator of financial market integration. It is based on the intuition that the more integrated the market is, the more bond yields should react to common factors instead of local factors.[26] In perfectly integrated markets, one would expect that common news is reflected one-to-one in the local yields, i.e., $\beta = 1$. A deviation of β from 1 indicates changes in the interest rate of the benchmark country are not fully reflected in the interest rate of the country j. This can result from the omission of an exchange rate adjustment term if exchange rate variations are not orthogonal to yields. Alternatively, it can result from changes in default and liquidity risk. Finally it can result from a separation of markets due to high transactions costs, which could result from capital controls, information barriers and other factors. Equation B-8 is estimated by OLS for a forward looking window of 500 business days. This provides a time series for the β and α coefficients.

We try to disentangle the different reasons for β to differ from one. In one set of regressions, we adjust for exchange rate changes as contracted in the exchange rate future markets. We therefore adjust our interest series by the swap rate difference $r_{it}^{adjusted} = i_{j,t,T} - (is_{j,t,T} - is_{g,t,T})$. A simple comparison of the dispersion of adjusted yields of EMU countries with non-adjusted yields shows that exchange rate adjustments are an important source of yield heterogeneity pre-EMU (Figures A-6 and A-7). Accordingly, we estimate

$$\Delta r_{it}^{adjusted} = \alpha_{it} + \beta_{it}\Delta r_{Bt} + \varepsilon_{it}, \tag{B-8}$$

This allows to compare the German Länder with EMU, the UK and the US.[27] However, it should be noted that this adjustment only eliminates the exchange rate changes as manifested in swap rates. It does not eliminate the risk of holding uncovered foreign bonds.

A second reason for β to deviate from one is liquidity risk, that is related to yield changes. Liquidity risk can be defined as the difficulty to buy and sell bonds in the markets. It can be particularly relevant if general risk aversion increases and investors prefer to invest in safe havens from which they can depart easily thanks to deep and liquid markets. We therefore also estimated

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[26]Such a news based measure is described, e.g., in Baele, Ferrando, Hördahl, Krylova, and Monnet (2004).

[27]A similar adjustment has been performed by Favero, Giavazzi, and Spaventa (1997) and Gómez-Puig (2006) in the context of an investigation of the determinants of sovereign bond spreads. However, it has not yet been used to adjust yields to estimate bond market integration.

the regression B-8 with an additional control variable for liquidity, the bid-ask spread.

Finally, default risk can be re-assessed when fiscal fundamentals of a country respectively Land change relative to the German central government. However, we believe that such changes occur relatively rarely as fiscal and macroeconomic fundamentals change slowly and rarely. It appears therefore very unlikely, that these changes would significantly alter estimation results based on daily data.

This measure is routinely calculated by the ECB to assess the degree of financial market integration in the European sovereign bond markets. However, the ECB employs monthly data to estimate the coefficients. In contrast, we estimate bond market integration on a daily basis. This means that we test, in how far a change of the Bund yield from one day to the next is reflect in the corresponding change of the yield of the other country/Land.

A prerequisite for bond markets to price in the information at such a frequency is a sufficiently high degree of information processing capacity and transparency. To gain further insights, we therefore also estimate the regressions at a lower frequency. More precisely, instead of defining Δ to be the one business day difference, we also compute Δ as a 5 days and a ten days difference.[28] Accordingly, we present all figures with the one day, five days and ten days frequency. The difference between the estimated β series at a one, five and ten days difference provides us with useful information on the speed with which market participants can process and acquire information. While it is also possible, that important macroeconomic news across countries/Länder are clustered in the same week but not on the same day, this should hardly explain differences of the estimated coefficients. Indeed, even at weekly frequency it is hard to think about many news releases that systematically occur in the same week but not the same day and that are so frequent as to explain huge differences. Instead it appears more plausible that a larger coefficient is really driven by the fact that the information manifested in the German interest rate takes time to be reflected in the other interest rate series.

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[28]The resulting autocorrelation in the residuals leaves the estimated βs unbiased. We perform Newey-West corrections of the standard errors and present the confidence bands with Newey-West standard errors in Figure C-15.

C Robustness check: OLS regressions

C.1 Main results

Figure C-1 plots the evolution of the average estimated β (according to Equation B-8) for 10 EMU countries. To be able to compare the results with the German federation, we adjusted pre-EMU yields by the swap spread. This allows to adjust for expected exchange rate changes and thereby renders the results more comparable to a unified monetary area such as Germany, where no exchange rate exist and the European Monetary Union itself.[29] As can be seen, the average level of integration increased in the run-up to EMU and is close to one since then. The level of measured integration is substantially higher, if one looks at one-week or two-weeks yield differences before EMU. A lower frequency of price differencing increases the estimated β from 0.4. to 0.7 in the early 1990s. During EMU, financial markets seem to react very quickly. In fact, the coefficient is almost identical for one-day, one-week or even two-weeks differences. Noticeably, during recent financial market turmoils, a slight decrease in the level of integration can be observed.

Our results indicate that the increasing level of integration is not only linked to the abolition of exchange rate risk as our data are adjusted for exchange rate expectations by swap spreads. Overall, our results for EMU confirm previous results by e.g. Baele, Ferrando, Hördahl, Krylova, and Monnet (2004), who showed a substantial increase in sovereign bond market integration and relate it to the introduction of the euro. The higher integration level might, however, also result from increased standardization of bond conventions, rendering them closer substitutes. It might also result from newly established electronic trading platforms, increasing price transparency in the bond market.

To further assess the impact of monetary union, relative to other factors, we look at US and UK bond yields. If the bond market integration shown in the previous section was due to monetary union, we would not expect to find a similar pattern in non-EMU data. However, as Figure C-3 demonstrates, also the UK experienced a sharp increase in integration-coefficient in the late 1990s.[30] Repeating the regressions with a lower frequency (one and two weeks)

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[29]Adjusting for swap spreads considerably lowers the heterogeneity of estimated βs in the euro area.

[30]The increase is also statistically significant, and the 95% confidence interval lies post
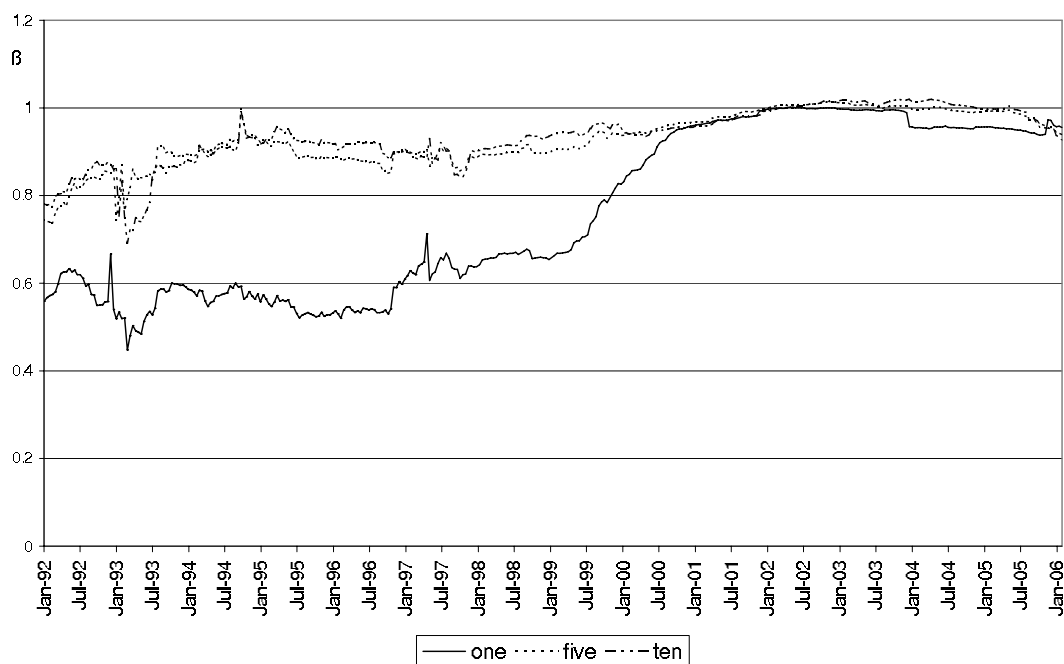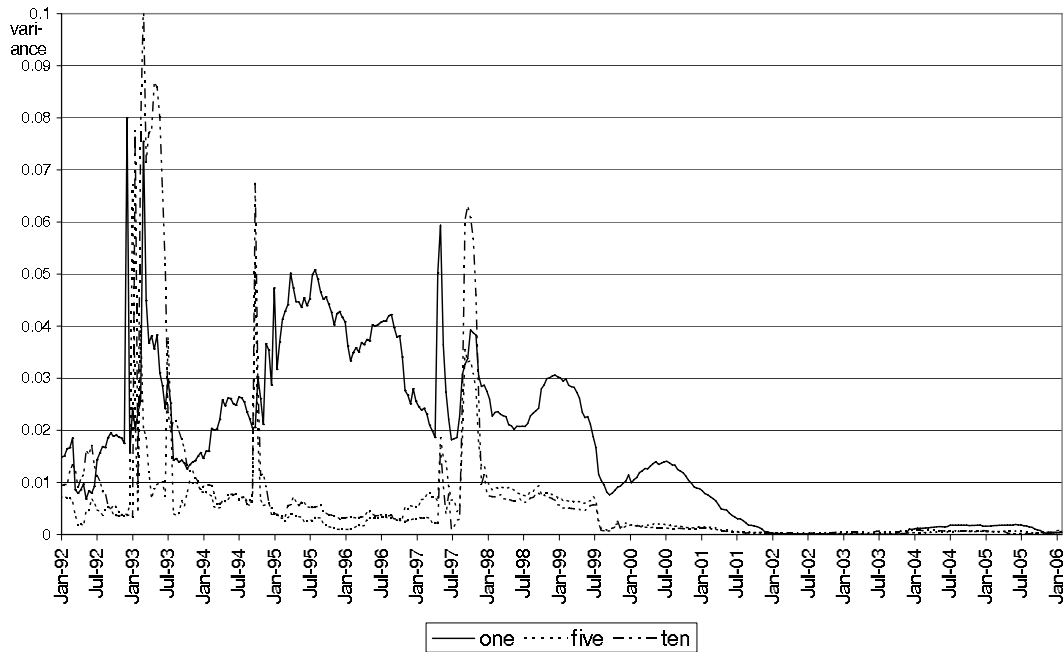
Figure C-1: Evolution of cross-sectional average β of EMU countries. ""one", "five", "ten" denote average betas for swap adjusted yields at a one, five and ten business days yield difference. Estimates are carried out on a forward looking window of 500 days. Source: Thomson Financial Datastream, own calculations.

yields a different picture. Here, bond market integration was already quite high in the early 1990s, but still increased further in the late 1990s to a level of one. Hence, on a weekly basis, price information revealed in the German Bund was almost completely reflected in Guilt yields. The much lower coefficients for daily yield changes suggest, that information processing capacities were limited in the early 1990s. Indeed, electronic trading platforms were only established in the mid to late 1990s. For example, Bunds and Guilts have been traded on the common BondVision platform as of 2001.[31] Since we estimate the regressions 500 business days forward looking, observations from 2001 enter already in the coefficient estimation of 1999.

We next turn to the same exercise with US data.[32] The overall level of integration, as one would expect, is significantly lower than within Europe. As is the case with British bonds, US paper appears to be more integrated when looking at lower frequencies. The integration coefficient is about 0.8 in the

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2000 very close around one.

[31]Cf. bondvision.net for details.

[32]The benchmark country is again Germany.

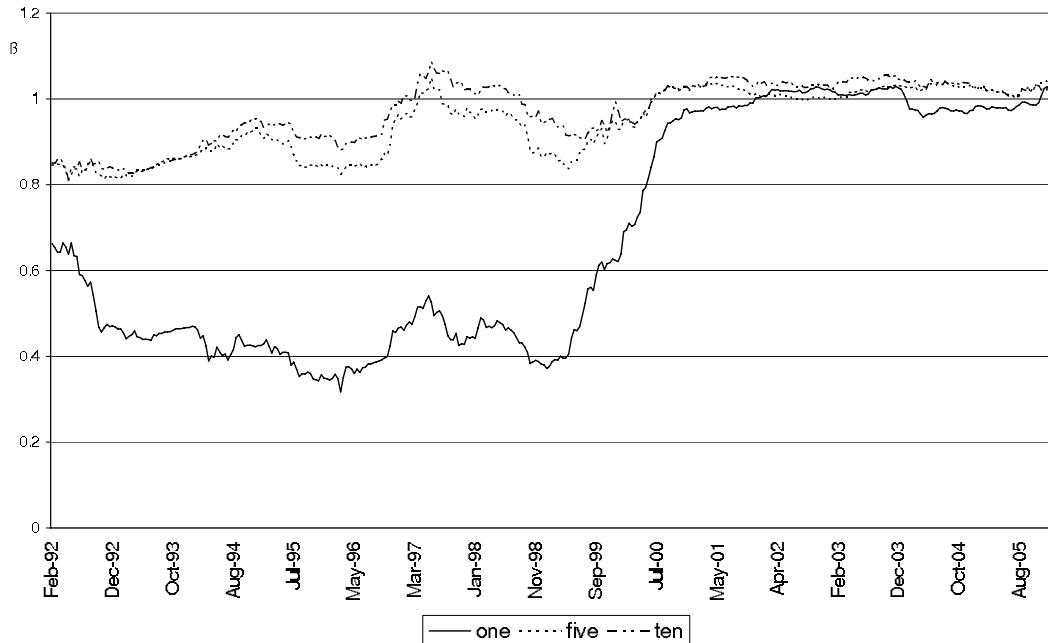Figure C-2: Evolution of cross-sectional variance of β for EMU countries. "one", "five", "ten" denote average betas for swap adjusted yields at a one, five and ten business days yield difference. Estimates are carried out on a forward looking window of 500 days. Source: Thomson Financial Datastream, own calculations. The spike in October 1997 for 10 day difference is driven by Greece.

early 1990s, dropping to 0.5 in 1999. From there on, integration increases past the original level. On a daily frequency, we observe a continuous increase since the mid 1990s, with a particularly steep slope from 1999 on. Foregoing swap spread correction, we find a more pronounced integration starting in 1999 at all frequencies. While the coefficient for daily yield changes finally approaches 0.7, the measure for lower frequencies reaches approximately one, as in the case with swap spread correction.

Adjusting yields by the spread of swap rates according to the uncovered interest rate parity, we control for the expected changes in exchange rates. Figure C-2, which depicts the cross sectional variance of the estimated coefficients for EMU-countries clearly shows the crisis int the European exchange rate system of the early to mid 1990s. Already from the mid 1990s, we observe a significant decline in heterogeneity among countries which later formed the EMU.

Figure C-5 depicts the results for the German Länder. It plots the evolution of the mean of the estimated β coefficients, which assess the impact of changes

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Figure C-3: Evolution of β for the UK. "one", "five", "ten" denote average betas for swap adjusted yields at a one, five and ten business days yield difference. Estimates are carried out on a forward looking window of 500 days. Source: Thomson Financial Datastream, own calculations.

in Bund yields on changes of the yield in Land i, across the 16 Länder. The results show that the level of integration is significantly smaller than for the EU central government bond market. Moreover, a strong increase in the level of financial market integration in the course of the 1990s can be observed. At a lower frequency of one week (five business days) or two weeks, Länder yields more and more co-move with the yield of the Bund, which hints at increased integration. Compared to central government bonds, we find that the level of sub-national bond market integration is much lower. Overall the results suggest that the dynamics of Länder yields is quite different from the dynamics of the central government yield. Our news-based measure of market integration points at significantly lower levels of integration in the German subnational government bond market than the euro area sovereign bond market. Especially at a high frequency of one day differences, integration is almost absent.

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Figure C-4: Evolution of β of the US. "one", "five", "ten" denote average betas for swap adjusted yields at a one, five and ten business days yield difference. Estimates are carried out on a forward looking window of 500 days. Source: Thomson Financial Datastream, own calculations.
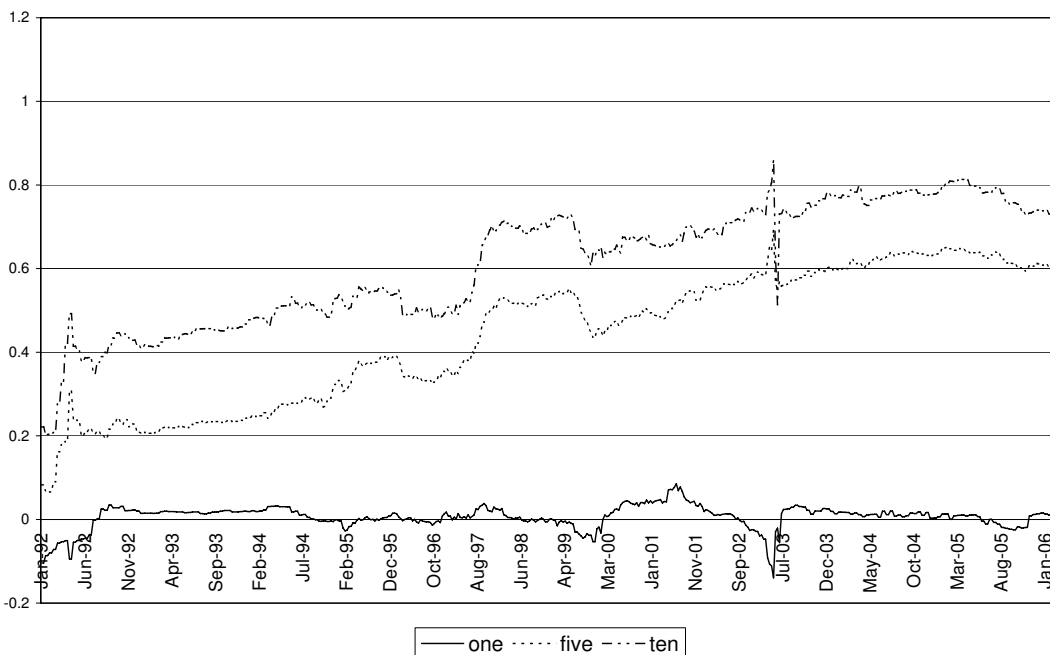
Figure C-5: Evolution of the cross-sectional mean of β. "one", "five", "ten" denote at a one, five and ten business day yield difference.

C.2   Further robustness checks

Figure C-6: Evolution of US β. Data are not swap rate adjusted. "one", "five", "ten" denote at a one, five and ten business day yield difference. Source: Thomson Financial Datastream, own calculations.
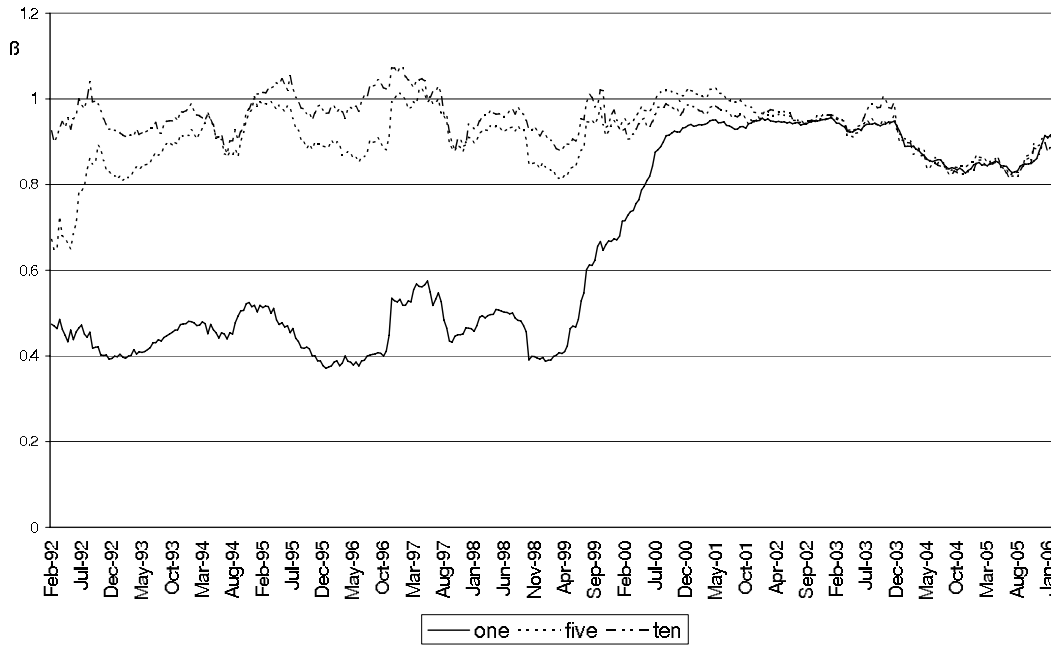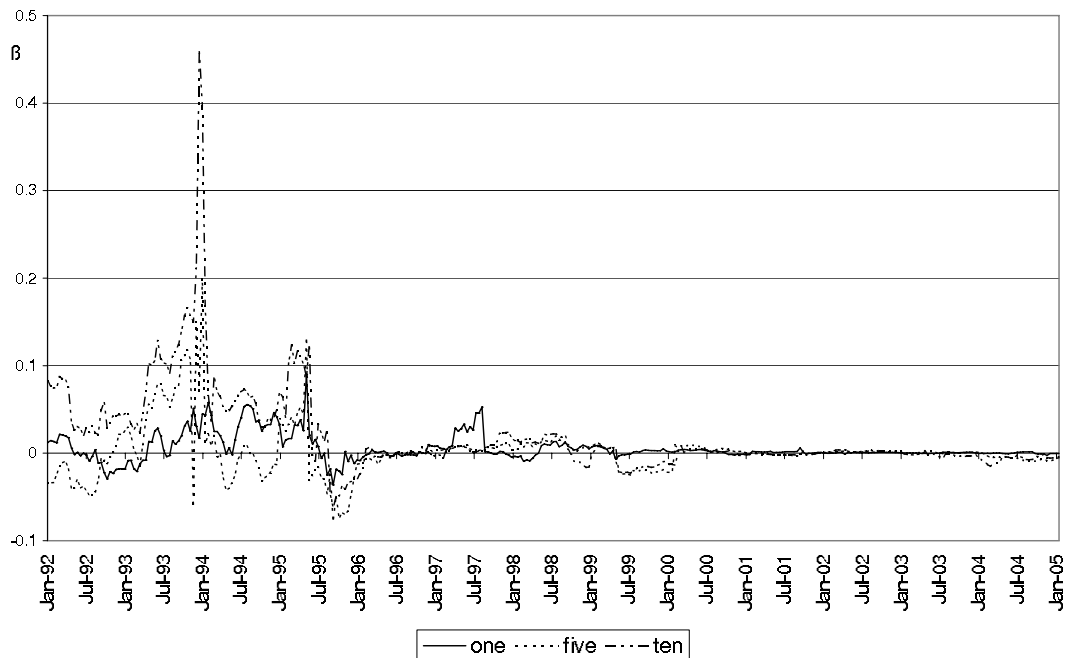
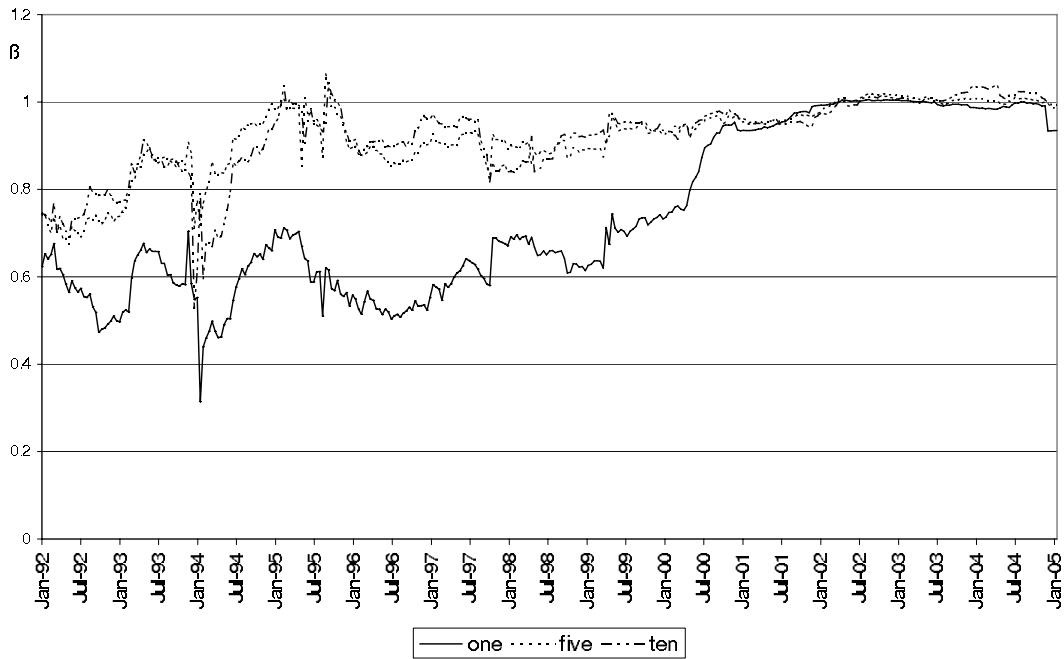Figure C-7: Evolution of UK β. Data are not swap rate adjusted. "one", "five", "ten" denote at a one, five and ten business day yield difference. Source: Thomson Financial Datastream, own calculations.
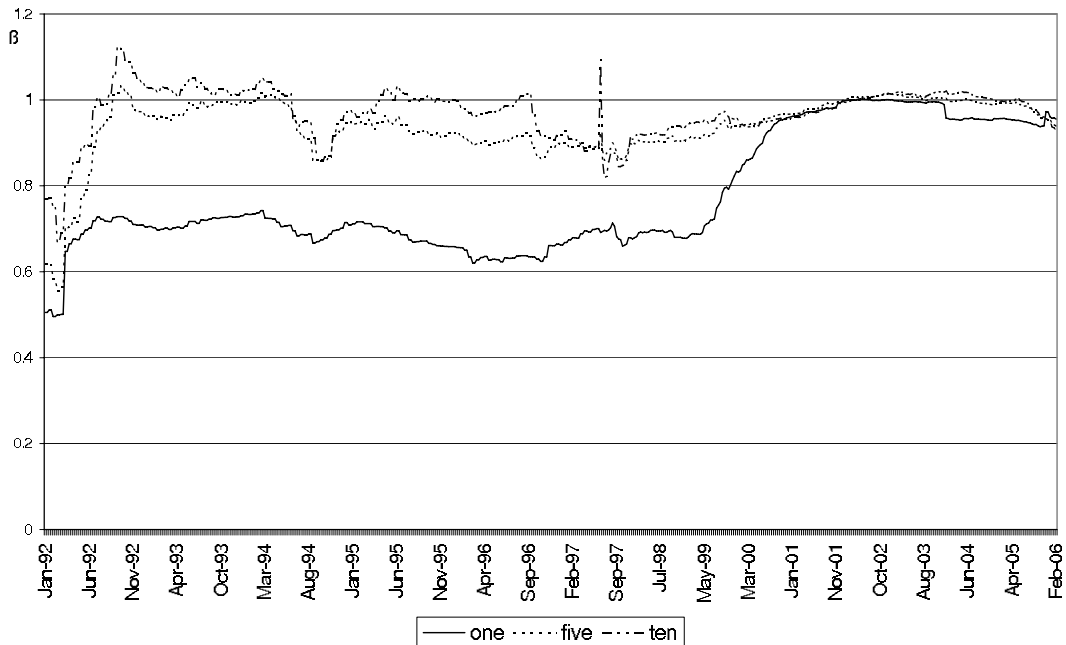
Figure C-8: Evolution of average βs of EMU countries. "one", "five", "ten" denote at a one, five and ten business day yield difference. Source: Thomson Financial Datastream, own calculations.
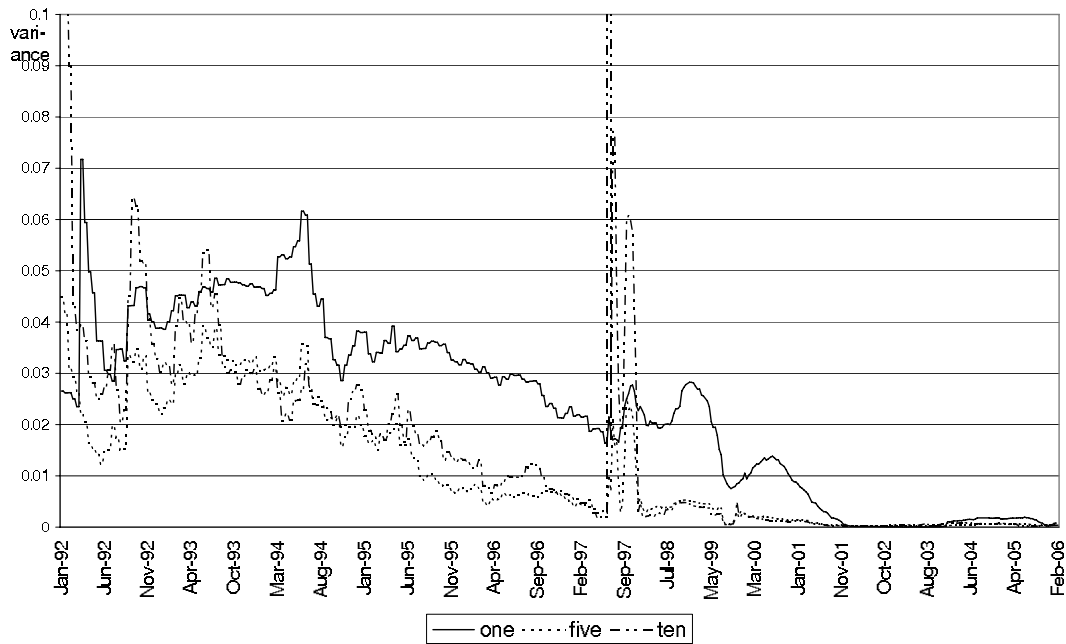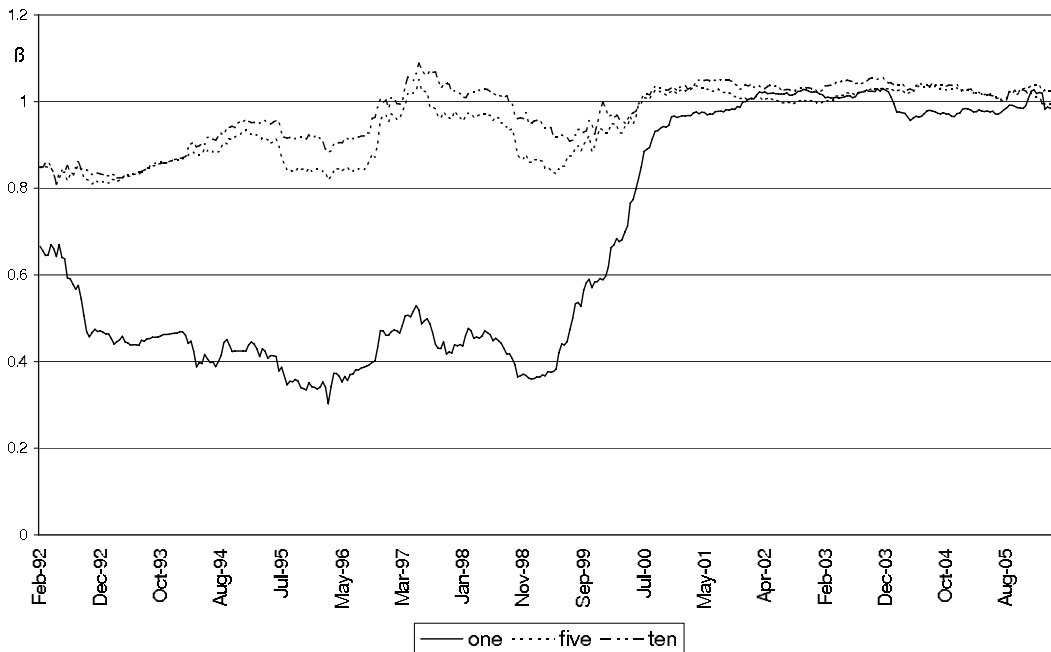
Figure C-9: Evolution of variance of βs of EMU countries. "one", "five", "ten" denote at a one, five and ten business day yield difference. Source: Thomson Financial Datastream, own calculations.

Figure C-10: Evolution of average coefficient on bid-ask spread of EMU countries. Yield data are swap adjusted, the bid-ask spread is included as additional control variable. "one", "five", "ten" denote at a one, five and ten business day yield difference. Source: Thomson Financial Datastream, own calculations.

Figure C-11: Evolution of average βs of EMU countries. Yield data are swap adjusted, the bid-ask spread is included as additional control variable. "one", "five", "ten" denote at a one, five and ten business day yield difference. Source: Thomson Financial Datastream, own calculations.
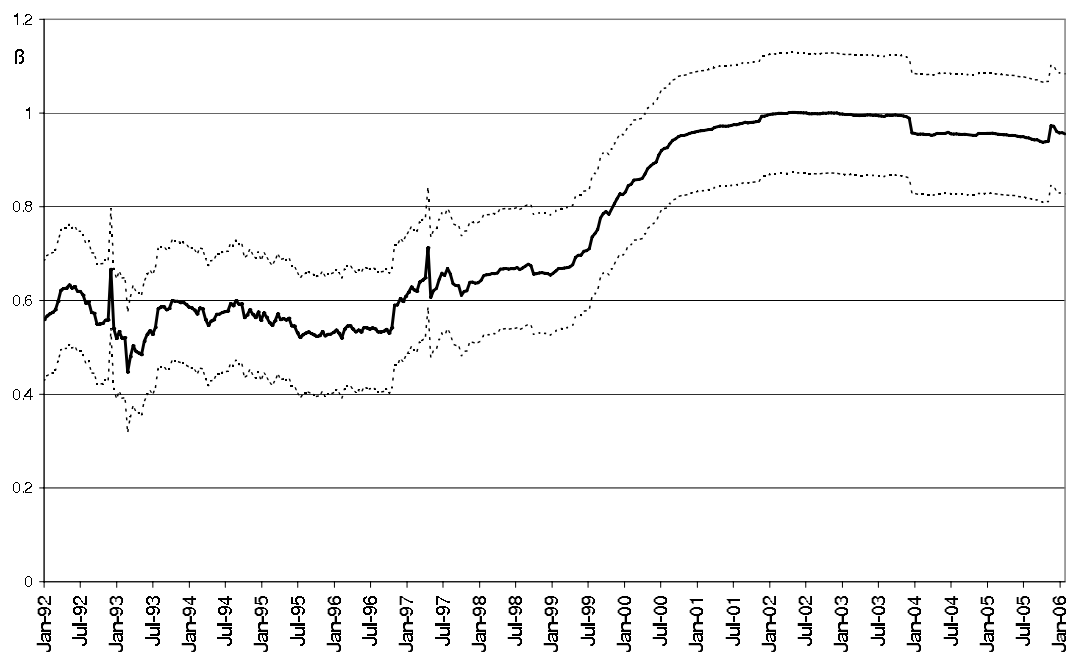

Figure C-12: Evolution of UK-β. Yield data are swap adjusted, the bid-ask spread is included as additional control variable. "one", "five", "ten" denote at a one, five and ten business day yield difference. Source: Thomson Financial Datastream, own calculations.
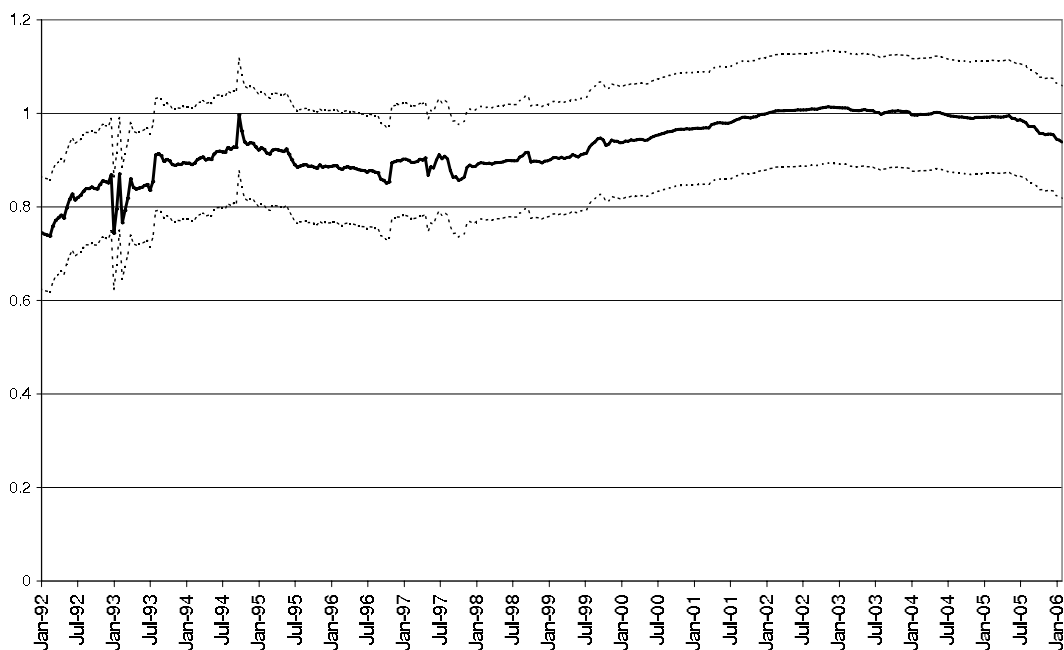
Figure C-13: Evolution of US-β. Yield data are swap adjusted, the bid-ask spread is included as additional control variable. "one", "five", "ten" denote at a one, five and ten business day yield difference. Source: Thomson Financial Datastream, own calculations.

Figure C-14: Evolution of average βs of EMU countries at a one day difference. Dashed lines give $\pm$ 1 Newey-West standard errors. Yield data are swap adjusted. "one", "five", "ten" denote at a one, five and ten business day yield difference. Source: Thomson Financial Datastream, own calculations.

Figure C-15: Evolution of average βs of EMU countries at a five days difference. Dashed lines give $\pm$ 1 Newey-West standard errors. Yield data are swap adjusted. Source: Thomson Financial Datastream, own calculations.
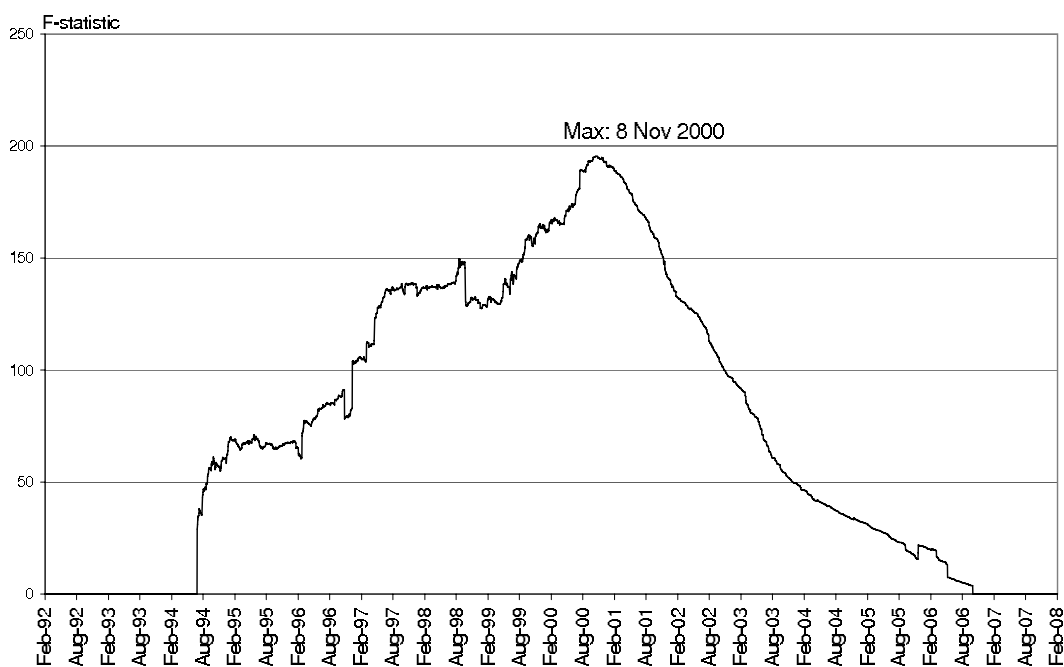

Figure C-16: F-statistic from Quandt-Andrews unknown breakpoint test. Unweighted mean across euro area countries without Luxembourg, Cyprus, Malta and Slovenia.
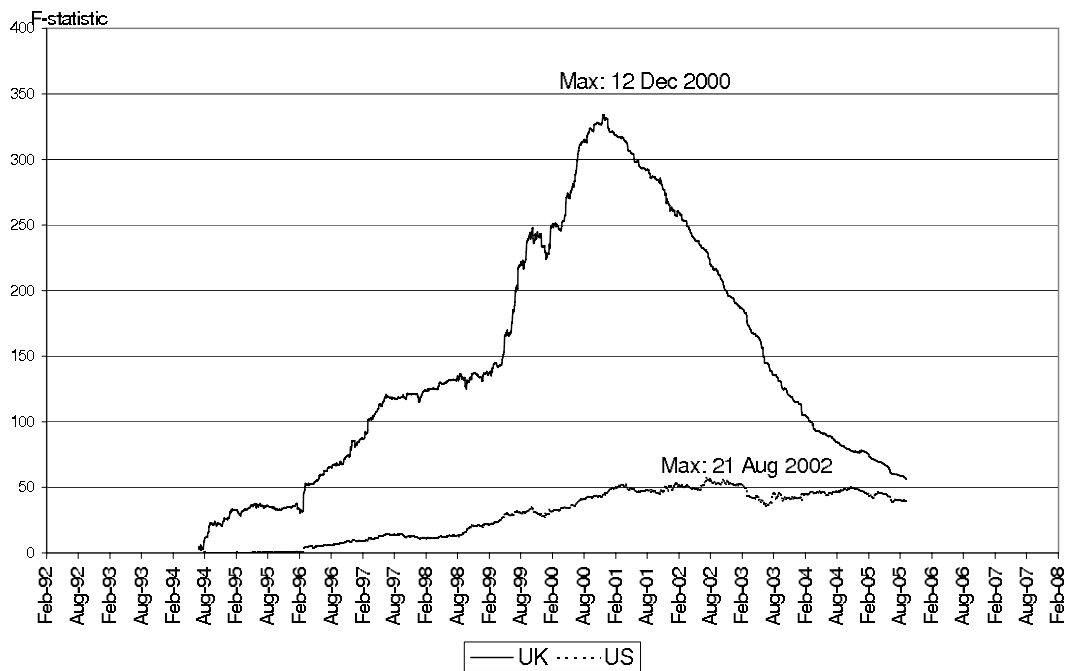
Figure C-17: F-statistic from Quandt-Andrews unknown breakpoint test for US and UK.

Table C-1: Maximum Wald F-statistic

	date	F
aus	10/10/1997	238.3
bel	9/14/2000	203.9
esp	2/25/1999	96.2
fin	10/6/1998	284.3
fra	10/31/2000	241.5
grc	1/31/2001	320.5
irl	12/6/2000	240.3
ita	3/6/2002	18.1
nld	9/14/2000	481.3
prt	1/4/2000	180.9
uk	12/12/2000	334.0
us	7/26/2002	57.3

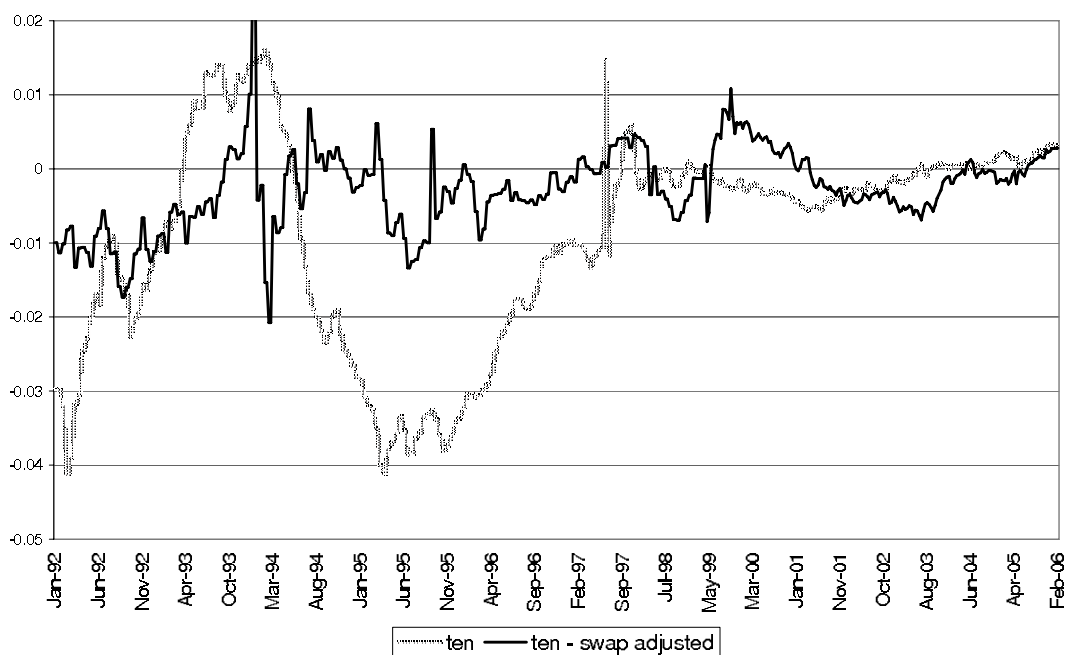*Notes:* Maximal F-value for Quandt-Andrews unknown breakpoint test.

Figure C-18: Evolution of average α of EMU countries at a ten days difference. Swap adjusted data vs non-swap adjusted data. Source: Thomson Financial Datastream, own calculations.
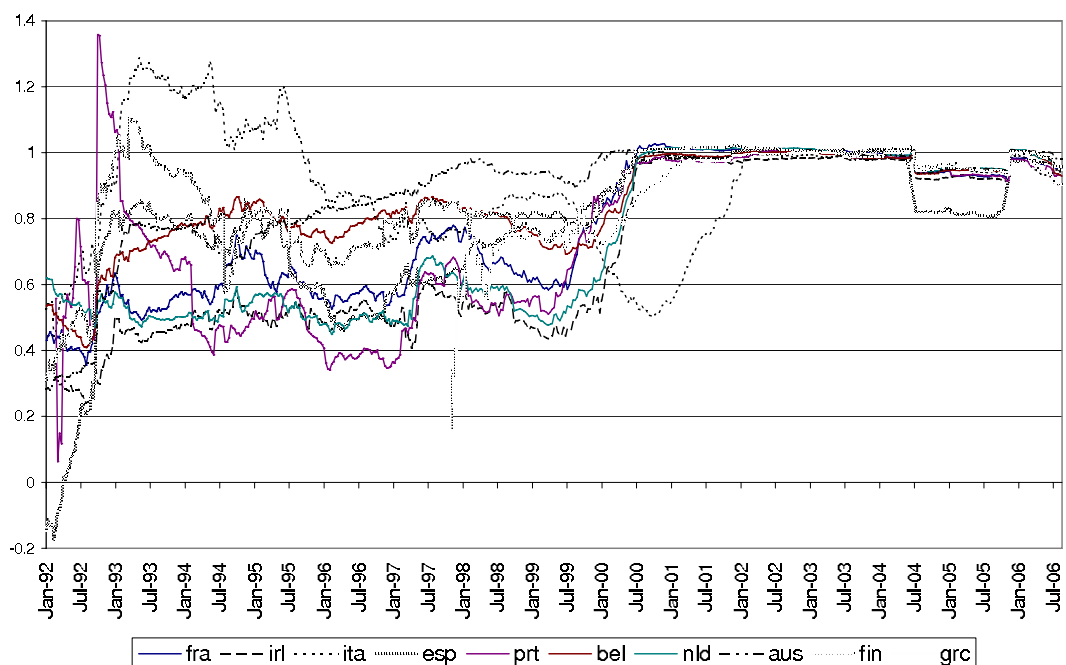

Figure C-19: Evolution of βs of EMU countries. Source: Thomson Financial Datastream, own calculations.
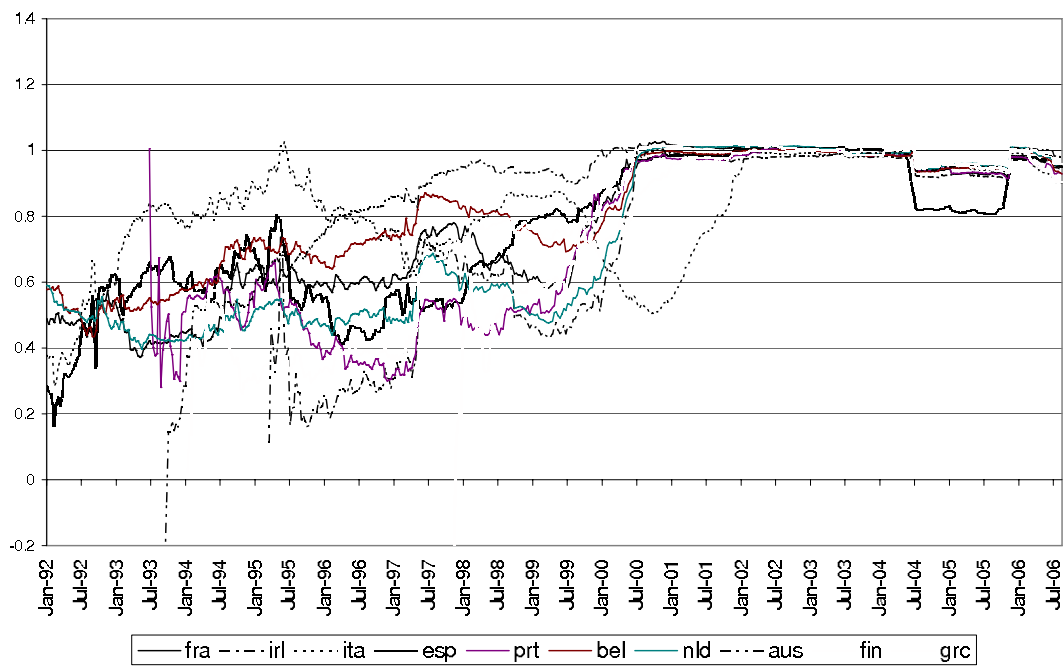
Figure C-20: Evolution of βs of EMU countries. Yields are adjusted for the swap spread to Germany to account for exchange rate change expectations. Source: Thomson Financial Datastream, own calculations.