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Spill-over effects of monetary policy – a progress report on interest rate convergence in Europe

Michael Flad
(Goethe University Frankfurt)

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Deutsche Bundesbank, Wilhelm-Epstein-Strasse 14, 60431 Frankfurt am Main,
Postfach 10 06 02, 60006 Frankfurt am Main

Tel +49 69 9566-1
Telex within Germany 41227, telex from abroad 414431

Please address all orders in writing to: Deutsche Bundesbank,
Press and Public Relations Division, at the above address or via fax +49 69 9566-3077

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Abstract

This study examines differences in the interest rate response to an ECB policy impulse in the euro area, the new EU-member states, and in the other non-eurozone EU countries in order to gauge the degree of interest rate alignment in Europe. To this end, PANIC, a *P*anel *A*nalysis of *N*on-stationarity in *I*diosyncratic and *C*ommon components, is employed in a structural factor set-up. Under the assumption that the ECB sets the short end of the yield curve, the analysis shows that: (i) The response of Europe's money and government bond markets to new information can be summarized by two common stochastic trends and one stationary common factor, which together explain more than 68% of the overall variation of the two market segments; (ii) one of the factor innovations can be associated with the ECB's policy stance, which strongly affects the short end of the euro area's yield curve; (iii) compared to the euro area, the short-term market segments in the new EU-member states react, on average, 12% more weakly to the monetary policy signal, whereas these countries' long-term government bond yields respond up to 25% more strongly to such a common innovation.

Keywords: Factor Models, Common Stochastic Trends, Interest Rate Channel, New Member States, Mixed Data Sampling.

JEL Classification: C33, E52, G15

Non-technical summary

The purpose of this study is to analyze the effects of the ECB's monetary policy on non-eurozone EU financial markets in order to assess the degree of interest rate convergence between the *N*ew *M*ember *S*tates (NMS) of the EU (Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, and Slovenia), the other non-eurozone EU countries (other-EU: Denmark, Sweden, and the U.K.), and the euro area.

The need for considering news that not only impact the eurozone's financial markets, but also might spill over to non-eurozone markets lends itself naturally to the *I*nternational *A*sset *P*ricing *T*heory (IAPT). At the heart of the IAPT is the view that a few pervasive factors are the dominant source of covariation among international asset returns. The theoretical IAPT model, however, cannot identify these economic forces a priori. In light of this, I employ the recently proposed PANIC methodology, a *P*anel *A*nalysis of *N*on-stationarity in *I*diosyncratic and *C*ommon components (Bai and Ng, 2004), in a structural factor set-up. The objective is to allow for the data to identify the joint factor structure and to characterize the factors and their innovations by their economic features.

To identify a euro area monetary policy impulse, I follow the identification scheme recently applied in Lippi and Thornton (2004). That is, I fix a rotation of the space spanned by the common factor shocks such that the policy impulse by the ECB first impacts the intermediate indicator of monetary policy (the overnight money market rate in the euro area) before it evolves through the money and government bond markets in Europe. Based on the extent to which the ECB's policy impulses spill over to the NMS' and other-EU countries' interest rate markets, I propose two measures to quantify the state of the convergence of these countries towards the euro area. The first measure deals with short-run effects and gauges the degree of interest rate alignment by investigating whether eurozone and non-eurozone EU interest rates respond symmetrically to monetary policy operations by the ECB in the short-run. The second measure focuses on the long-run and consists of the long-run proportion of each non-eurozone country's interest rate change explained by the ECB's monetary policy.

In a nutshell, the findings are as follows: a monetary policy impulse is recovered, which exerts a strong influence on the slope of the yield curve in Europe. It explains 68% of the common variability at the short end and 71% of the common variability at the long end of the yield curve in the euro area, in the NMS, and in the other-EU countries. This monetary impulse is further shown to spill over to financial markets in the NMS. However, different financial market segments in the NMS are shown to have attained different levels of convergence: the short-term interest

rates react especially weakly to the ECB's operations (on average −12%), whereas the long-term government bond yields' responses to an ECB impulse range from +14% to +25%.

Nicht-technische Zusammenfassung

Dieses Arbeitspapier analysiert die Effekte der EZB-Geldpolitik auf die EU-Finanzmärkte außerhalb der Eurozone, um den Grad der Konvergenz der Zinsen zwischen den NMS und dem Eurogebiet zu bestimmen und diesen mit dem der anderen EU-Staaten, die ebenfalls nicht Mitglied der Eurozone sind (andere EU-Staaten: Dänemark, Schweden, und das Vereinigte Königreich), zu vergleichen.

Die Berücksichtigung von Wirtschaftsnachrichten, die nicht nur die Finanzmärkte der Eurozone, sondern auch Märkte außerhalb des Eurogebiets beeinflussen, legt die Anwendung der *I*nternational *A*sset *P*ricing *T*heory (IAPT) nahe. Dieser liegt zugrunde, dass einige wenige fundamentale Faktoren die gemeinsame Bewegung von internationalen Renditen treiben. Allerdings kann im Rahmen der IAPT der ökonomische Ursprung dieser Faktoren nicht a priori bestimmt werden. Vor diesem Hintergrund wende ich den PANIC-Ansatz (Bai and Ng, 2004), eine *P*anel *A*nalysis of *N*on-Stationarity in *I*diosyncratic and *C*ommon components, im Kontext eines strukturellen Faktormodells an. Ziel ist es, aus den Daten selbst die gemeinsame Faktorstruktur zu bestimmen und die Faktoren und deren treibende Schocks durch ökonomische Eigenschaften zu kennzeichnen. Der geldpolitische Impuls im Eurogebiet wird mittels des Schemas von Lippi and Thornton (2004) identifiziert. Im Speziellen wird der Raum, den die gemeinsamen Faktorschocks aufspannen, so rotiert, dass der geldpolitische Impuls zuerst den Tagesgeldzinssatz ändert, bevor sich dieser dann im Geldmarkt und im Markt für Staatsanleihen widerspiegelt. Aus der Art und Weise, wie der geldpolitischen Impuls der EZB auf die Finanzmärkte der NMS und der anderen EU-Staaten einwirkt, werden darauf folgend zwei Kennzahlen zur Messung der Angleichung von Zinssätzen abgeleitet. Die erste Kennzahl zielt auf die kurzfristigen Effekte der Geldpolitik ab und bestimmt den Grad der Angleichung der Zinsen anhand des Vergleichs ihres kurzfristigen Verhaltens im und außerhalb des Eurogebietes nach geldpolitischen Maßnahmen der EZB. Die zweite Kennzahl bezieht sich auf die längeren Effekte und misst den Anteil der EZB-Entscheidungen an der Änderung der Zinsen in den Ländern außerhalb der Eurozone.

Die Ergebnisse der Untersuchung lassen sich wie folgt zusammenfassen: ein geldpolitischer Impuls wird bestimmt, der im hohen Maße das kurze Ende der Zinskurve in Europa beeinflusst und unmittelbar 68% und auf lange Sicht 71% der gemeinsamen Bewegung der Zinsen im Eurogebiet, in den NMS und in den anderen EU-Staaten erklärt. Es wird desweiteren gezeigt, dass der geldpolitische Impuls die Finanzmärkte der NMS beeinflusst, dass jedoch einzelne Marktsegmente in den NMS einen unterschiedlichen Grad an Konvergenz mit dem Eurogebiet erreicht haben. So reagieren die kurzfristigen Zinsen im Schnitt 12% schwächer auf einen Impuls der EZB, wohingegen die Renditen von Staatsanleihen um +14% bis +25% stärker antworten.

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1 Introduction

The purpose of this study is to analyze the effects of the ECB's monetary policy on non-eurozone EU financial markets in order to assess the degree of interest rate convergence between the New Member States (NMS) of the EU (Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, and Slovenia), the other non-eurozone EU countries (other-EU: Denmark, Sweden, and the U.K.), and the euro area. In principle, there are three channels through which the ECB's changes in policy rates or liquidity conditions already affect non-eurozone financial markets. The first is the most obvious one. The ECB's decisions are relevant for other central banks if these target their exchange rate against the euro. The second channel works through the interdependence in the real sector and makes the euro area's economic news (e.g., the monetary policy decisions by the ECB) provide valuable information about the economic outlook for the rest of the EU. The third channel consists of investors that diversify their portfolios internationally. They exploit any arbitrage possibilities and a change in the monetary policy in the euro area will affect financial markets in the NMS and the other-EU countries via capital flows.

The need for considering information that not only influences the eurozone's financial markets, but also might spill over to non-eurozone markets lends itself naturally to the International Asset Pricing Theory (IAPT). With the additional assumption that exchange rates follow the same structural dependence as the asset returns, Ross and Walsh (1983) and Solnik (1983) extend the standard arbitrage pricing theory by Ross (1976) into an international setting. At the heart of the IAPT is the view that a few pervasive factors are the dominant source of covariation among international asset returns. The theoretical IAPT model, however, cannot identify these economic forces a priori.

* Correspondence: Michael Flad, Johann Wolfgang Goethe-University Frankfurt/Main, Mertonstr. 17-21, D-60054 Franfurt/Main, Germany, Tel: +49(69)798-25161, Fax: +49(69)798-22788, Email: flad@wiwi.uni-frankfurt.de. The views expressed in this paper are those of the authors and do not necessarily reflect the opinion of the Deutsche Bundesbank. The research for this paper was conducted while I was visiting the Economic Research Center of the Deutsche Bundesbank. I would like to thank the Deutsche Bundesbank, especially Heinz Herrmann, for kind hospitality. I wish to thank Sandra Eickmeier for providing me with parts of her codes and suggestions. Also, thanks to Jörg Breitung, Uwe Hassler, Lutz Kilian, Wolfgang Lemke, Christian Schumacher, and the seminar participants at the Deutsche Bundesbank as well as the conference participants at the Spring Meeting for Young Economists 2006 in Seville, Spain, the DStatG-Pfingsttreffen 2006 in Hamburg, Germany, and the Meeting of the Verein für Socialpolitik 2006 in Bayreuth, Germany for valuable comments and discussion. All errors are mine.

In light of this, I employ the recently proposed PANIC methodology, a Panel Analysis of Non-Stationarity in Idiosyncratic and Common components (Bai and Ng, 2004), in a structural factor set-up. The objective is to allow the data to identify the joint factor structure and to characterize the factors and their innovations by their economic features. Unlike traditional multivariate time-series models of cointegration, common trends and cycles, PANIC is a method with which a large number of interest rates and yields can be represented in terms of a few common (non-stationary) factors and their shocks as well as an idiosyncratic component − without appealing to stationarity or cointegration assumptions. It further renders the possibility of an economically meaningful interpretation of the factors by rotating the space spanned by the common factor shocks.

On the methodological side, this study is related to both the literature on modeling bond yields and applications of large-scale structural dynamic factor models. The literature on modeling bond yields dates back to the work by Steeley (1990) as well as Litterman and Scheinkman (1991) and suggests that the entire yield curve moves primarily in response to a few common (latent) factors. More recently, Rudebusch and Wu (2004) and Piazzesi (2005) analyze the nature of yield curve components for the U.S. and Fendel (2004) and Hördahl et al. (2005) for Germany in further detail. They support the macroeconomic view of a central bank as controlling the short end of the term structure of interest rates. The literature on large-scale factor models has been introduced by Stock and Watson (1988, 2002) as well as Forni et al. (2000), and has been extended to a structural set-up by Giannone et al. (2002, 2005). Studies that employ these factor models in the context of monetary policy or the term structure of interest rates are, for example, Sala (2003), Cimadomo (2003), Lippi and Thornton (2004), and Mönch (2005). The first three studies investigate the monetary transmission, whereas the latter focuses on no-arbitrage models to forecast the yield curve.

Regarding the financial convergence of the NMS towards the euro area, there are only few studies on co-movements across financial markets in the new and established EU members. Schmitz (2004) and Angeloni et al. (2005) belong to the few studies which examine financial convergence of the NMS into the euro area, and only Kim et al. (2005) directly analyzes the degree of convergence of government bond markets. While these studies find that the conditions for full monetary integration have not been reached, they either focus on the financial structure and the conduct of monetary policy, or apply time varying and dynamic correlation measures. An assessment of how the ECB's monetary policy stance affects non-eurozone financial markets and the implication thereof for the interest rate harmonization in Europe is lacking so far.

This study specifically addresses the linkages between interest rates in the NMS, in the other-EU countries, and in the euro area. It analyzes the cross-country asymmetries in the response of non-eurozone financial markets to the ECB's monetary policy to gauge the degree of interest rate alignment in Europe. Towards this end, it goes beyond the literature in three major aspects.

First, using five years of daily data spanning the recent history of the NMS, I exploit the co-movement among the money, and the government bond markets in the euro area, the NMS, and the other-EU countries to determine common factors and stochastic trends which explain the bulk of the variability of these markets.

Second, based on the macroeconomic view of a central bank controlling the short end of the yield curve, I identify a common monetary policy impulse. In particular, I follow the identification scheme applied in Lippi and Thornton (2004) and fix a rotation of the space spanned by the common factor shocks such that the ECB's changes in monetary policy first affect the overnight money market rate (as an intermediate indicator of monetary policy) before they are transmitted to other interest rates in the system. To explore the findings in further detail, I conduct a robustness check and investigate how potential ECB-surprises affect the term structure of interest rates.

And third, I gauge the degree of interest rate harmonization by examining differences in the extent to which the ECB's policy impulses spill over to the NMS' and the other-EU countries' financial markets. In particular, I propose two measures to quantify the state of interest rate alignment. The first measure is based on the implication that if financial markets in the EU were fully converged, news relevant to all EU financial markets (such as the ECB's policy impulses) would have symmetric short-run effects on interest rates and yields across EU financial markets. That is, the more symmetric the short-run effects of such monetary impulses, the higher the degree of alignment. The second measure builds on the notion that in fully harmonized financial markets, yields and interest rates should mainly be driven by common news (such as monetary policy signals). The second measure of alignment is therefore the long-run proportion of each non-eurozone country's interest rate variation explained by the ECB's monetary decisions.

The remainder of this study is structured as follows: in Section 2, I present the non-stationary methodology and the structural set-up. Section 3 focuses on the empirical analysis and shows that the response of interest rates and yields to news in eurozone and non-eurozone countries can be condensed to two common stochastic trends and one stationary common factor. A common monetary policy impulse is recovered, which exerts a strong influence on the slope of the yield curve in the euro area. It is further shown that different financial market segments in the NMS have attained different levels of alignment. A summary of these findings and concluding remarks are provided in Section 4.

2 Methodology

The framework underlying the analysis of this study is the IAPT. Since the basic IAPT model is well known, I will concentrate my discussion on the non-stationary factor analysis and the structural identification of the ECB's policy stance.

2.1 Model set-up and estimation

Let $X_t = [X_{1,t}, ..., X_{N,t}]'$ denote a vector collecting all interest rate series at time t, each of which has a factor structure of the following form $(i = 1, ..., N; \;\; t = 1, ..., T)$

$$X_{i,t} \;\; = \;\; c_i + \lambda_i' F_t + e_{i,t}. \tag{1}$$

Correspondingly, the interest rates and yields can be decomposed into three components: c_i is a constant, $\lambda_i' F_t$ is the common component with the $(r \times 1)$-dimensional vector of latent common factors $F_t = [F_{1,t}, ..., F_{r,t}]'$ as well as the corresponding $(r \times 1)$ latent loading vector $\lambda_i = [\lambda_{i,1}, ..., \lambda_{i,r}]'$, and $e_{i,t}$ is the series-specific stochastic error. More precisely, the common factors and idiosyncratic terms shall follow autoregressive processes, viz

$$A(L)F_t \;\; = \;\; u_t, \tag{2}$$

$$(1 - \rho_i L)e_{i,t} \;\; = \;\; \varepsilon_{i,t}, \tag{3}$$

where L is the usual lag-operator and $det[A(L)]$ with $A(L) = I_r - \sum_{j=1}^{p} A_j L^j$ has only roots on or outside the complex unit circle. The vector u_t of common shocks consists of r independent white noise increments with $var(u_t) = I_r$ and $\varepsilon_{i,t}$ is a well-defined zero-mean covariance-stationary process. While the errors $u_t, \varepsilon_{i,t}$, and the loadings λ_i are mutually independent across i and t, $\varepsilon_{i,t}$ itself might be weakly cross-sectionally dependent, making this model an approximate factor model. For further technical assumptions, see Bai and Ng (2004).

In the case of interest rates and yields, pretesting for the presence of non-stationarity is necessary because even if F_t were observed, the regression of $X_{i,t}$ on F_t would be spurious if $e_{i,t}$ is non-stationary. Bai and Ng (2004) show how the loading vector λ_i can be estimated by the method of principal components without imposing stationarity of cointegration restrictions. The crucial point is to estimate the common factors as the principal components of suitably transformed data. Denoting $\tilde{X}_t$ as the first-differentiated data, the first r factors are given by

$$\hat{F}_t = \sum_{s=2}^{t} \hat{f}_s, \tag{4}$$

where $\hat{f}_t = \frac{1}{\sqrt{N-1}} \hat{W} \tilde{X}_t$ is the principal component estimator with $\hat{W}$ as the $(r \times N)$ matrix of eigenvectors corresponding to the r largest eigenvalues of the sample covariance matrix of $\tilde{X}_t$. The factors are then accumulated to remove the effects of possible overdifferentiation which might bring about a (MA-)unit root in first-differences. For a rigorous account of assumptions on consistency, see Bai and Ng (2004). To render operative the above procedure, the number r of factors is usually estimated by minimizing Bai and Ng's (2002) weakly consistent information criteria.

Assuming that there is more than one factor driving the interest rates and yields in the system, individually testing the factors for the presence of a unit root will overstate the number of non-stationary factors r_1 (where $r_1 = r - r_0$ and r_0 denotes the number of stationary factors). Only the space spanned by the factors can be estimated, and linear combination of I(0) and I(1) factors can remain I(1). Hence, Bai and Ng (2004) motivate two modified variants of the statistics developed by Stock and Watson (1988) to determine the number of basis functions spanning the non-stationary space of F_t. The first one, $MQ_f(m)$, filters the factors F_t under the assumption that they can be represented as a finite order VAR(p)-process. The second statistic, $MQ_c(m)$, corrects for serial correlation of arbitrary form among the factors by non-parametrically estimating the factor innovations u_t. A detailed description of the algorithm to determine the dynamic properties of the common factors is given in the Appendix A. Note, in particular, if $r_1 \neq 0$, there exists a matrix $\hat{G} = [\hat{\beta}', \hat{\beta}'_\perp]'$ [1] with which the space of the common factors can be rotated such that the first r_1 elements of $\hat{G}\hat{F}_t$ are I(1) and the remaining r_0 factors are I(0).

2.2 Structural factor representation

The factor loadings λ_i and the common factors F_t in (1) and (2) are only identified up to a nonsingular transformation. This means that the original model can be written as

$$\begin{aligned} X_{i,t} &= c_i + \lambda_i^{*'} F_t^* + e_{i,t}, && (5) \\ A^*(L) F_t^* &= u_t^*, && (6) \end{aligned}$$

[1] Where the $(r \times r_1)$ submatrix $\hat{\beta}$ satisfies $\hat{\beta}'\hat{\beta} = I_{r_1}$ and $\hat{\beta}'\hat{\beta}_\perp = 0$.

with $\lambda_i^{*\prime} = \lambda_i^{\prime} R^{-1}$, $F_t^* = RF_t$, $A^*(L) = RA(L)R^{-1}$, and $u_t^* = Ru_t$ where R is an arbitrary non-singular square matrix of rank r. One way of dealing with this rotational indeterminacy is to follow traditional factor analyses and assume orthonormal factors such that R equals to the identidy matrix. Alternatively, one could determine R in the style of structural VAR analyses and think of R as embodying an economic model with structural shocks $u_t^* = Ru_t$. For the latter purposes, let me specify v_t as the residual of the VAR

$$A(L)\hat{\digamma}_t \;=\; v_t, \quad \text{with} \quad \hat{\digamma}_t = [\underset{(r_1\times 1)}{\Delta(\hat{\beta}'\hat{F}_t)},\; \underset{(r_0\times 1)}{\hat{\beta}_\perp'\hat{F}_t}]', \tag{7}$$

where $\hat{\digamma}_t$ is a vector rotated by $\hat{G}$ whose first r_1 elements are first-differentiated such that equation (7) forms a stationary VAR. Then, the vector of common shocks $\hat{u}_t$ is recovered by the spectral orthogonalization

$$\hat{u}_t \;=\; (\hat{P}\hat{Q}^{1/2})^{-1}\hat{v}_t, \tag{8}$$

where $c\hat{o}v(\hat{v}_t) = \hat{P}\hat{Q}\hat{P}'$ with $\hat{P}$ consisting of the eigenvectors and $\hat{Q}$ of the corresponding eigenvalues. As a result, the first r_1 orthogonal common shocks can be attributed to the common stochastic trends among the r common factors without imposing an additional structure, e.g., via a Cholesky factorization where different conclusions can be drawn by an alternative ordering of the factors.

Finally, I identify the structural shocks $\hat{u}_t^*$ by following the recent procedure in factor analyses (see, e.g. Giannone et al., 2002), and define R as an orthonormal rotation matrix $R(\theta) = \prod_{m=1}^{r} R_m(\theta_m)$ which performs a rotation in the plane spanned by $\hat{u}_t$ over the r angles contained in the vector $\theta = [\theta_1, ..., \theta_r]'$ with $\theta_1, ..., \theta_r \in [0, \pi]$. Assuming a monetary tightening, I choose the rotation angle vector θ such that the monetary policy impulse is a factor innovation that, on average, first impacts the overnight money market rate and then affects other interest rates and yields in the system (for a similar approach, see Lippi and Thornton, 2004).[2] More technically speaking, I am interested in the parameter-vector $\vartheta = [\theta, m]'$ that maximizes the following objective criterion

$$\hat{\Pi}(\theta, m) \;=\; \left\{ \hat{\psi}_{i^*,m}(h=0|\theta) - \frac{1}{\iota'\iota}\iota'\hat{\Psi}_m(h=0|\theta) \right\}, \tag{9}$$

where ι is a selection vector whose elements equal to zero for $i^* = \{\textit{overnight rate}\}$ and one otherwise, and $\hat{\Psi}_m(h=0|\theta)$ is the column vector of interest rate responses to the factor innovation

[2] Taking for granted that there are $r > 1$ common shocks driving the system of interest rates, only a row of R in $u_t^* = Ru_t$ is identified.

m ($m = 1, ..., r$) on impact (i.e., $h = 0$). The factor innovation identified by the parameter-vector $\hat{\vartheta}$ such that the objecitve function $\hat{\Pi}(.)$ reaches a maximum will then be denoted as the ECB's monetary policy signal.

Note, in particular, that the impulse response $\hat{\psi}_i(h)$ of the ith variable to the structural shocks $\hat{u}_t^*$ at horizon h is given by

$$\hat{\psi}_i(h) = \hat{\lambda}_i' \hat{B}_h \hat{P} \hat{Q}^{1/2} R, \tag{10}$$

with $\hat{B}_h = \tilde{A}_1 \hat{B}_{h-1} + ... + \tilde{A}_j \hat{B}_{h-j} + ... + \tilde{A}_p \hat{B}_{h-p}$ for $h = 1, 2, ...,$, $\hat{B}_0 = I_r$, and $\hat{B}_h = 0$ for $h < 0$, and where, in accord with equation (7), $\tilde{A}_j$ is defined as $\tilde{A}_j = [\tilde{A}_{r1,j} : \tilde{A}_{r0,j}]$ with

$$\begin{aligned} &\tilde{A}_{r1,j} \text{ for } \quad m = 1, ..., r_1 : \tilde{A}_{m,j} = \hat{A}_1 + I_{r \times r_1}, \tilde{A}_{m,j} = \hat{A}_{m,j} - \hat{A}_{m,j-1} \;\; \forall \;\; j = 2, ..., p-1, \\ &\qquad\qquad\qquad \text{and } \tilde{A}_{m,p} = -\hat{A}_{m,p-1}; \\ &\tilde{A}_{r0,j} \text{ for } \quad m = r_1 + 1, ..., r : \tilde{A}_{m,j} = \hat{A}_{mj} \;\; \forall \;\; j = 1, 2, ..., p, \end{aligned} \tag{11}$$

such that $\hat{\psi}_i(h)$ gives the impulse response $\hat{\psi}_i(h)$ of the ith variable to the structural shocks $\hat{u}_t^*$ in levels.

3 Empirical Analysis

3.1 Data and preliminary remarks

The data-set covers two broad interest rate categories: money market rates and government bond yields. In total, $N = 118$ nominal interest rates for all euro area member states (excluding Greece), the euro area aggregate, the other-EU countries, and the NMS (excluding Cyprus, Malta, and Slovenia) are analyzed from January 04, 2001 through December 30, 2005 ($T = 1825$, excluding bank holidays).[3] The reason for choosing this sample is data availability. Money market rates (from overnight up to twelve months) as well as government bond redemption yields for two, five, seven, and more than ten years (usually 20 to 30 years) were downloaded from Datastream. All interest rates and yields are converted to euros under the assumption of risk-neutral investors. A detailed list of the data-series, their treatment, and other details regarding the implementation are given in the Appendix B.

[3] I use nominal interest rates and yields because, for real interest rates to converge, purchasing power parity has to hold. Testing whether real interest rates converge across EU-countries would thus be a joint test of the convergence of interest rates and purchasing power parity.

The empirical analysis is conducted in Matlab. To assess the statistical significance of the degree of cross-country heterogeneity in the responses of interest rate in both the NMS and the other-EU countries to an ECB impulse, I consider bootstrapped 90% confidence intervals. The bootstrap procedure entails 1000 replication and is based on the factor-autoregressive representation (equation (7)).

3.2 Common factors and their dynamic properties

To start with the factor analysis, Panel (a) of Table 1 shows the cumulative percentage share of total variance of the first-differentiated data explained by the first eight factors, whereby the maximum number of principal components is chosen according to Bai and Ng (2002) as $r_{max} = 8\text{ceil}\left(\frac{\min(N,T)}{100}\right)^{1/4}$. In order to determine the number of estimated factors, I have computed the six criteria suggested by these authors, but each of the information criteria gives the upper bound for the number of estimated factors. Hence, I rely on a similar heuristic criterion as used in Forni et al. (2000) and set $\hat{r} = 3$ because the fourth principal component explains less than 5% of the overall variance of the sample. Indeed, the first three factors capture 68% of the overall variance in the sample. For the maximum number of principal components, I also calculated the fraction of common variation (i.e., the variance of the common component) explained by the factor innovations for interest rates in first differences. As outlined in Table 1 (Panel b), adding the third factor innovation substantially increases the fraction of common variance by 11 percentage points, whereas the rest of the factor innovations individually explain less than 5 percentage points of the common variation.

Table 1: Selecting the number of common factors F_t

(a): Total variance of interest rate changes explained by principal components

No. of factors	Total variance explained (cumulated)
1	0.53
2	0.62
3	0.68
4	0.72
5	0.74
6	0.77
7	0.80
8	0.82

(b): Fraction of common variation explained by factor innovations for interest rates and yields (in first differences)

No. of factor innovations	Cumulative fraction of common variation explained[a]
1	0.60
2	0.69
3	0.80
4	0.84
5	0.88
6	0.92
7	0.96
8	1.00

Note: [a] Forecast error variance decomposition with respect to the rth factor at horizon $h_{max} = 100$.

Coming to the dynamic properties of the common factors, Table 2 reports the statistics $MQ_c(m)$ and $MQ_f(m)$ for testing F_t along with the critical values given in Bai and Ng (2004). Both statistics cannot reject the null-hypothesis of two integrated common factors spanning the non-stationary space of the panel and therefore provide evidence of non-stationary interest rates and yields in the euro area, the NMS, and the other-EU countries for the sample period under study.[4]

Table 2: Dynamic properties of common factors

$H_0 : r_1 = m$ integrated common factors

m	MQ_c [a]	MQ_f [b]	Bai and Ng (2004) critical values for $MQ_{c,f}$ at significance level		
			0.01	*0.05*	*0.10*
1	-5,42	-6.99	-20.151	-13.730	-11.022
2	-13,82	-15,92	-31.921	-23.535	-19.923
3	-29,69	-36,76	-41.064	-32.296	-28.399

Note: [a] Based on Bartlett-Window.
[b] Based on VAR(1)-process.

[4]For a robustness check, I have tried several alternative specification for both test-statistics and found for $MQ_c(m)$ that the result of two common stochastic factors is neither sensitive to the choice of the time domain kernel (the quadratic spectral kernel or the Box-Car kernel in place of the Bartlett-Window) nor the bandwidth. Likewise, the outcome of two common trends does not depend on the order of the underlying VAR(p) in the design of $MQ_f(m)$.

The choice of $\hat{r} = 3$ common factors and their dynamic property of being partly integrated is consistent with other studies on factors driving the yield curve. The yield curve literature usually applies a three-factor decomposition to capture the variation of the yield curve (see e.g. Steeley, 1990). Moreover, in their paper on U.S.-treasury bond yields, Hall et al. (1992) report too small a cointegration rank as suggested by the rational expectations hypothesis of the term structure. This implies the existence of more than one single common non-stationary trend. Carstensen (2003) presents a simple theoretical model of the term structure of interest rates that allows for two or fewer non-stationary factors. He supports his theoretical model with empirical evidence for Germany. In addition, Fendel (2004) finds three, very persistent, latent factors for German interest rates with the first and second factor having monthly autocorrelations close to unity.

3.3 Identifying the monetary policy impulse

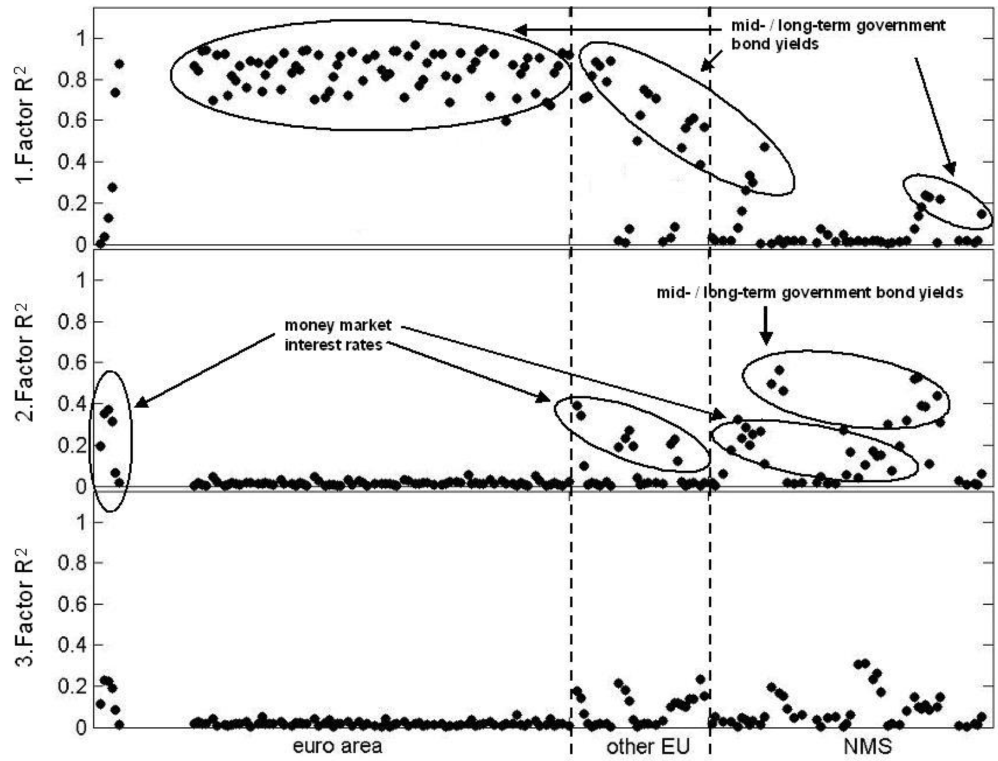
In order to make a tentative interpretation of the factors, Figure 1 shows the R^2 from regressing each variable in the data-set on each factor (both data and factors adjusted to be stationary). A large R^2 indicates that the factor under analysis explains a relatively large portion of the variation in that particular variable or, put differently, that the variable is a component of the respective factor. The results indicate that the first factor consists of mid- and long-term government yields. The second factor is related to money market rates and government bond yields in the NMS. The third factor has a similar interpretation.

Regarding the monetary policy impulse, I first estimate a VAR of factors (equation (7)) of lag order four chosen by minimizing the Akaike and Schwarz information criteria. Next, I rotate the $\hat{r} = 3$ dimensional orthogonolized factor shocks by parameterizing the orthonormal rotation matrix R as

$$R(\theta) = \begin{pmatrix} cos(\theta_1) & sin(\theta_1) & 0 \\ -sin(\theta_1) & cos(\theta_1) & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} cos(\theta_2) & 0 & sin(\theta_2) \\ 0 & 1 & 0 \\ -sin(\theta_2) & 0 & cos(\theta_2) \end{pmatrix} \cdot \cdot \begin{pmatrix} 1 & 0 & 1 \\ 0 & cos(\theta_3) & sin(\theta_3) \\ 0 & -sin(\theta_3) & cos(\theta_3) \end{pmatrix}, \quad (12)$$

where $\theta = [\theta_1, \theta_2, \theta_3]'$ is the rotation angle vector with $\theta_1, \theta_2, \theta_3 \in [0, \pi]$. As is well known, the set of possible identifications is uncountable with this choice of orthogonalization and rotation. For this reason, I grid the interval $[0, \pi]$ into 30 points to search effectively over the space of orthogonal decompositions for the shock $\hat{u}_t^*$ that conforms to the identification scheme. The candidate identification comprises $\hat{\theta}^* = [\frac{21}{30}\pi, \frac{27}{30}\pi, \frac{1}{5}\pi]'$ and implies that the second (rotated) structural shock best mimics a monetary policy impulse by the ECB.

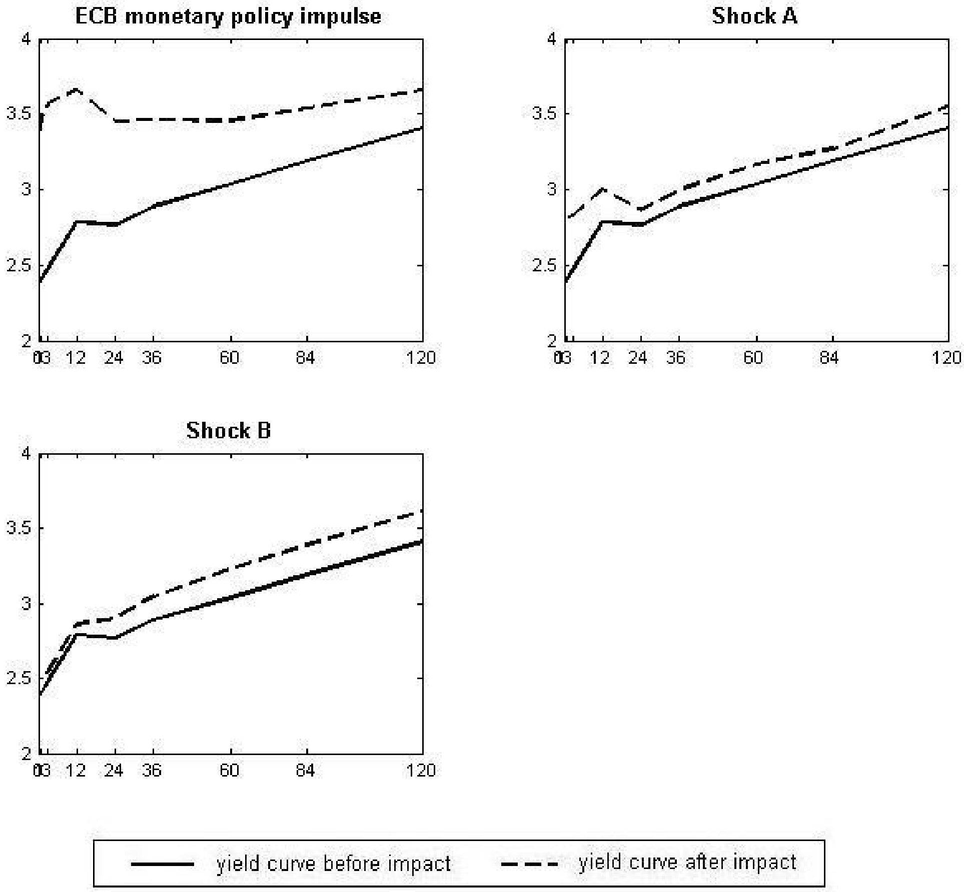
Figure 1: Explanatory power of factors



Note: R^2 from regressing each variable in the data-set on each factor (both data and factors adjusted to be stationary). The horizontal axes represents the individual interest rates for the euro area, the other EU countries, and the NMS.

Furthermore, I conduct a robustness check along the following dimension: recent economic and finance studies have verified the macroeconomic view of a central bank that controls the short end of the yield curve (see, e.g., Hördahl et al, 2005, who find for Germany that monetary policy surprises exert a strong influence on the slope of the yield curve). Figure 2 displays the response of the yield curve for the euro area to each structural shock (where, for presentative reasons, the effects correspond to a ten-standard-error shock). The extracted monetary policy signal has a strong effect on the short- end of the yield curve, while the other two structural shocks predominantly affect the level of the yield curve.

Figure 2: Monetary policy effects on euro area's yield curve



Note: The horizontal axes is the maturity in months. The effects of the structural shock are "stylized" in the sense that the effects of ten-standard-error shocks are reported for presentative reasons.

Finally, to give more insight about the evolution of the recovered ECB's policy impulse at different points along the yield curve, Table 3 presents the fraction of common component variance explained by this policy innovation. Several features of this forecast error variance decomposition stand out. First, the monetary policy impulse strongly affects all rates and yields. The forecast error variance explained for all series increases from approximately 68% on impact to more than 71% at the 24-month horizon. Second, the monetary policy innovation explains more forecast error variance of money market rates than of long-term government bond yields. On impact, more than 90% of the overnight rate can be attributed to monetary policy, whereas the policy impulse accounts for roughly 44% of the long-term yield's forecast error variance. Having said

Table 3: Monetary policy impulse and its evolution along the yield curve

Fraction of common variation explained

Horizon	euro area interest rates and yields								Average
(months)	*overnight*	*1-month*	*3-months*	*12-months*	*2-years*	*5-years*	*7-years*	*10-years*	over all series
impact	0.9041	0.9049	0.9274	0.9342	0.9058	0.8034	0.6892	0.4445	0.6824
1	0.8864	0.8906	0.9144	0.9301	0.9074	0.8142	0.7226	0.5521	0.7039
2	0.8794	0.8846	0.9081	0.9272	0.9071	0.8185	0.7348	0.5852	0.7093
3	0.8774	0.8828	0.9060	0.9258	0.9068	0.8200	0.7388	0.5953	0.7111
4	0.8770	0.8824	0.9054	0.9253	0.9066	0.8203	0.7398	0.5978	0.7118
5	0.8770	0.8824	0.9053	0.9252	0.9065	0.8203	0.7399	0.5981	0.7123
6	0.8771	0.8824	0.9053	0.9252	0.9065	0.8202	0.7398	0.5980	0.7125
12	0.8771	0.8825	0.9053	0.9252	0.9065	0.8202	0.7398	0.5980	0.7126
24	0.8771	0.8825	0.9053	0.9252	0.9065	0.8202	0.7938	0.5980	0.7126

that, the explanatory power of the policy innovation slightly diminishes for money market rates, but markedly raises for the long term rate with an increasing forecast horizon. In the long-run, i.e., at the 24-month horizon, approximately 88% of the overnight rate and roughly 60% of the long-term government bond yield are explained by the monetary impulse.

3.4 Assessing the degree of interest rate convergence

To provide a bird's eye view of the trend of the NMS' and the other-EU countries' interest rate alignment, Figure 3 shows, along the same lines as the work done by Baele et al. (2004), the cross-country dispersion of interest rate differentials for the NMS, the other-EU countries, and the euro area. Since interest rates and yields with identical characteristics equalize in perfectly coverged financial markets, the cross-country dispersion of interest rate spreads with the euro area average can be used as an indicator of how far away the various market segments are from full convergence. The cross-country dispersion at time t across n countries c takes the following form

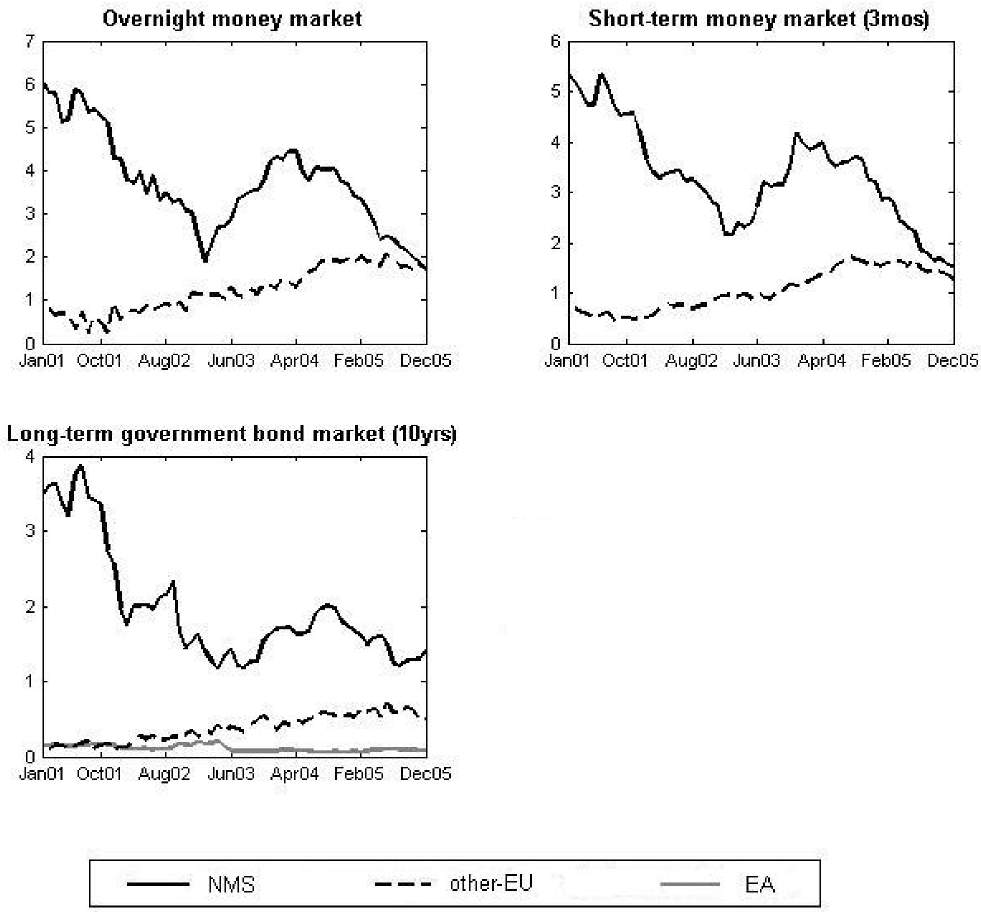
$$Disp_t^X = \sqrt{\frac{1}{n}\sum_c \left(X_{c,t} - X_{EA,t}\right)^2}, \tag{13}$$

where $X_{c,t}$ is the interest rate or yield for each country belonging to either the NMS, the other-EU countries, or the euro area, and $X_{EA,t}$ is the euro area rate or aggregate. The higher the degree of interest rate alignment, the lower the dispersion.[5] With the advent of EU-membership (in May 2004), the NMS' interest rates and yields began to converge towards the euro area. This, however, might also reflect a matching of fundamentals. Convergence in economic policies has probably led to a harmonization of inflation expectations across the NMS, and the entry of three additional NMS[6] into the Exchange Rate Mechanism II in May 2005 caused a decline in risk premia. Notwithstanding this policy coordination, the differentials in the overnight market segment seem to be very high for the NMS (in the beginning of the sample almost six to seven percentage points), whereas they decline for interest rates with longer maturities (e.g., approximately three to four percentage points in the long-term market segment in 2001). By contrast, the cross-country dispersion of interests rates differentials for the other-EU countries are low but not declining, and range around one percentage point over the sample period.

[5] Using the euro area aggregate as a benchmark might induce spurious convergence results among eurozone countries (i.e., lower dispersion) because the euro area aggregate is usually computed as a weighted average of the individual eurozone member's data. Nonetheless, I set as benchmark the eurozone aggregate and not an individual country because the ECB targets the euro area as a whole.

[6] Cyprus, Latvia, and Malta.

Figure 3: Cross-country dispersion of interest rates and yields



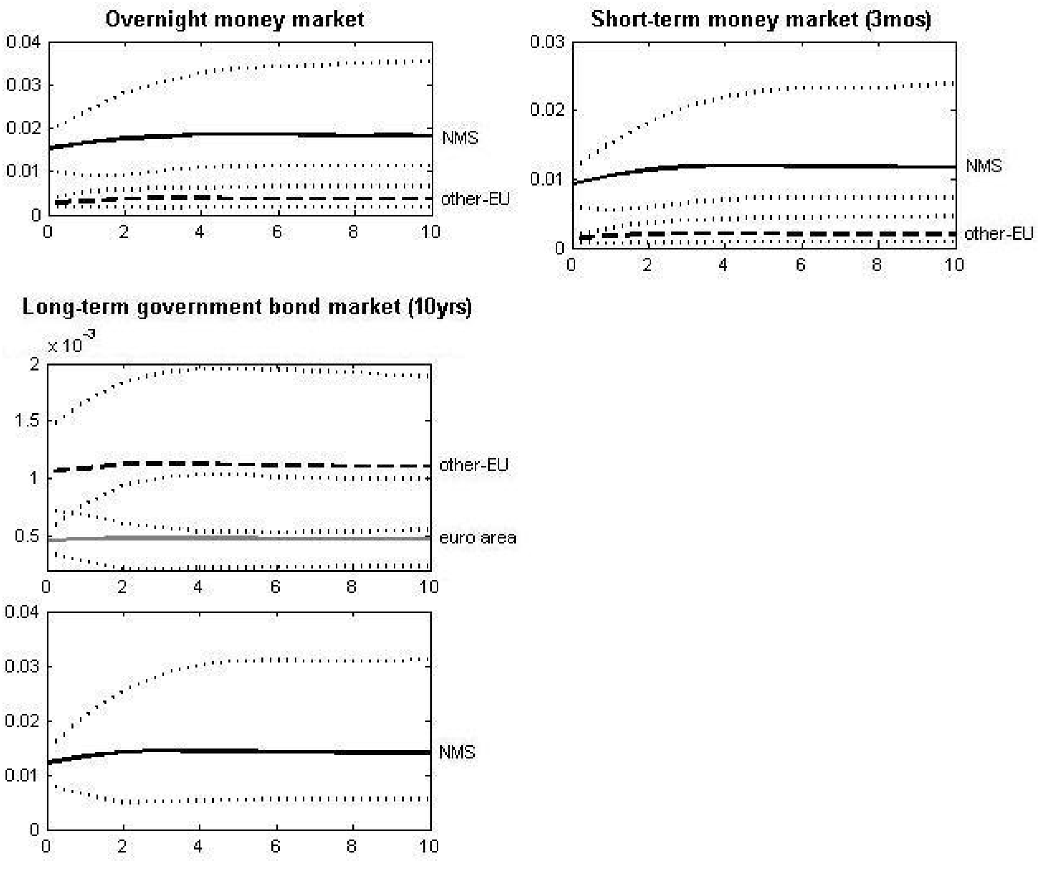
Note: For the sake of clarity, only the overnight market, the short-term money market, and the long-term government bond market are shown. The cross-country dispersion for the other interest rates are available upon request.

The NMS' progress in interest rate convergence cannot be isolated per se from the effects of the concurrence of inflationary expectations, the investors' risk perception, or the liquidity of the individual countries. Financial convergence implies, however, that interest rates and yields should substantially react to innovations relevant to all markets (like the monetary policy signal by the ECB). Regarding the short-run effects of such common innovations, this implies that the interest rate alignment can be measured by investigating whether monetary policy operations by the ECB impact on eurozone and non-eurozone markets in a symmetric manner. The more symmetric the short-run effects of such a monetary impulse, the higher the degree of convergence. To this end, I calculate the cross-country dispersion of the response to a monetary policy impulse, similarly to the cross-country dispersion of interests rate spreads, as

$$Disp^{IRF}(h) = \sqrt{\frac{1}{n}\sum_{c}\left(\hat{\psi}_c(h) - \hat{\psi}_{EA}(h)\right)^2}, \tag{14}$$

where n and c as before, $\hat{\psi}_c(h)$ denotes the interest rate response to the monetary policy impulse at horizon h for each country belonging to either the NMS, the other-EU countries, or the euro area, and $\hat{\psi}_{EA}(h)$ is the interest rate response to the monetary signal for the euro area aggregate.

Figure 4: Cross-country dispersion of the response to a monetary policy impulse



Note: The median is in a solid line and 90% confidence intervals are in dashed lines. The horizontal axes is the forecast horizon in months.

As shown in Figure 4, the dispersion of short-run interest rate responses to an ECB policy impulse across the NMS under consideration is almost ten times larger than across the other-EU countries and the euro area. Kim et al. (2005) arrive at a similar conclusion. They find at least medium short-run dynamic interdependence between the Czech Republic, Hungary, and Poland on the one hand, and established eurozone countries on the other hand. Compared with these results, the short-run responses of the other-EU countries to a monetary signal by the ECB are not very heterogeneous. The dispersion is very low and almost coincides with that among the eurozone members. In the long-term segment, for example, the confidence bands of the dispersion among other-EU countries overlap with those of the euro area and comprise almost all of the euro area members' median dispersion. With respect to the euro area's long-term government bond market, the dispersion across the member countries is very low and close to zero, indicating almost fully converged short-run reactions of the eurozone's long-term bond market to policy operations by the ECB.

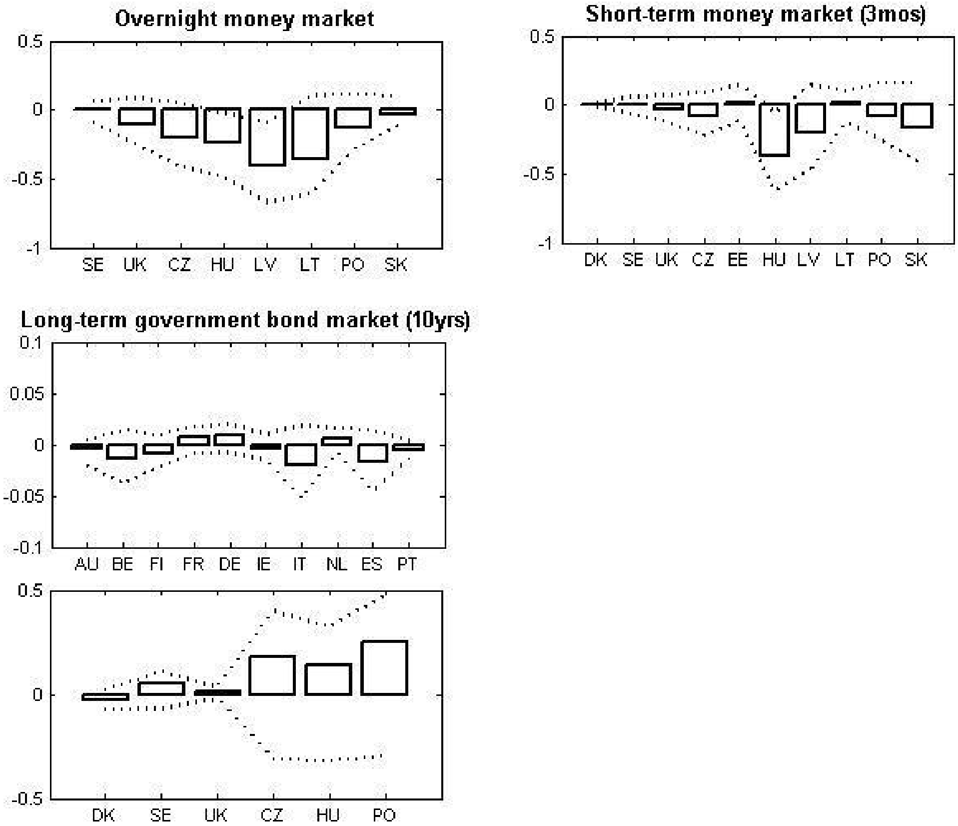
Regarding the long-run, common news (like the monetary policy impulse) should substantially drive local interest rates in harmonized financial markets. That is, a second measure of alignment is given by the long-run proportion of each country's interest rate changes explained by the ECB's monetary decisions. To make comparisons easier, I relate each country's long-run proportion of interest rate variation explained by the monetary policy signal to that of the euro area, i.e.,

$$Varexpl_c^{MP} = \left(\hat{\varpi}_c(\infty) - \hat{\varpi}_{EA}(\infty)\right), \tag{15}$$

where $\hat{\varpi}_c(\infty)$ and $\hat{\varpi}_{EA}(\infty)$ stand for each country's and for the euro area's long-run proportion of interest rate variation explained by the ECB's monetary policy impulse, respectively. A positive difference means that the monetary policy signal drives the country's interest rate more strongly than the euro area aggregate, whereas a negative difference indicates a relatively weaker long-run effect of such common information. Figure 5 summarizes this measure. The policy impulse by the ECB weakly spills over to non-eurozone overnight markets. While the ECB's operations have the same long-run effect on the Swedish overnight rate as on the overnight rate in the eurozone, it affects the Hungarian and the Latvian overnight markets to a statistically significant lesser extent. Compared to the long-run effect on the overnight rate in the euro area, the overnight interest rates of the considered NMS react, on average[7], 23% more weakly to a monetary impulse by the ECB, with Latvia (-40%) and Lithuania (-36%) having the smallest proportion of overnight interest rate changes that is explained by an ECB policy impulse. The same holds for the 3-month segment

[7]Calculated on the numbers given in Figure 5 - details available upon request.

Figure 5: Difference in the long-run proportion of interest rate changes explained by the monetary policy impulse



Note: For country-abbreviations see Data-Appendix. The median is in a solid line and 90% confidence intervals are in dashed lines. For the sake of clarity, only the overnight market, the short-term money market, and the long-term government bond market are shown for the countries for which the respective interest rates are available.

where, compared to the euro area, almost all non-eurozone countries are less affected by such a monetary impulse (on average -12%) and where, in the case of Hungary, the explained proportion of variance is significantly lower by 37%. The muted interest rate harmonization in the NMS' short-term market segments might imply that the NMS still face the challenge of accomplishing their domestic goals of economic development and market-oriented reform which brings about an individual monetary policy for each NMS that differs from that applied by the ECB. As regards the long-term government bond market, the differences in the long-run effects of the ECB's policy across eurozone countries are negligible (on average, the euro area countries react -0,01% weaker than the euro area aggregate). On the other hand, the monetary impulse considerably spills over to the NMS' long-term markets – though the effect is not statistically significantly different from the euro area benchmark (as indicated by the wide confidence intervals). The strong reaction of long-term rates, especially in Poland (+25%) and the Czech Republic (+18%), might imply that euro area news provides valuable information about the economic outlook for the NMS with the long-term term market segment mainly pricing in this information. For example, a tighter monetary policy in the euro area leads, ceteris paribus, to higher long-term interest rates in the eurozone. This might, in turn, have positive spill-over effects on long-term interest rates in the NMS by causing the NMS' risk premia to increase.

Overall, these findings confirm the descriptive analysis of the trend of the NMS' and the other-EU countries' interest rate alignment. Even though the ECB's policy impulse affects financial markets in the NMS (especially in the long-term bond segment), the convergence of the NMS towards the euro area seems to be muted (especially as regards the short-term market segments). In contrast, the interest rate convergence of the other-EU countries towards the euro area is, with respect to all market segments, rather progressed.

4 Concluding remarks

This study provided an empirical analysis of the spill-over effects of the ECB's monetary policy to non-eurozone financial markets in order to assess how far the interest rates in the NMS and in the other-EU countries have already converged towards the euro area. To this end, I employed Bai and Ng's (2004) PANIC procedure in a structural factor set-up. On the one hand, this approach allows for the dynamics of the large-scale system of European interest rates to be presented in terms of a few factors that are common to the whole system and an idiosyncratic component that is variable specific. On the other hand, the common factors and idiosyncratic components can be estimated consistently without appealing to stationarity assumptions and/or cointegration restrictions. Thus, the extraction of common trends can be isolated from the issue of testing stationarity. To identify a common monetary policy impulse, I fixed a rotation of the space spanned by the common factor innovations such that the policy signal first impacts the intermediate indicator of monetary policy (the overnight money market rate in the euro area) before it propagates through the money and the government bond markets in Europe. Based on the extent to which the ECB's policy impulses spill over to the NMS' and other-EU countries' financial markets, I introduced two measures to quantify the state of the interest rate alignment between these countries and the euro area. The first measure deals with the short-run effects of the monetary impulses by the ECB and gauges the degree of convergence by investigating whether eurozone and non-eurozone interest rates respond symmetrically to monetary policy operations by the ECB. The second measure regards the long-run and consists of the long-run proportion of each non-eurozone country's interest rate changes explained by the ECB's monetary decisions.

Based on five years of daily data spanning the recent history of the NMS, my analysis showed that two stochastic trends and one stationary factor are enough to capture more than 68% of the overall variance of eurozone and non-eurozone interest rates and yields. The identified monetary policy impulse exerts a strong influence on the slope of the yield curve in the euro area, i.e., it mainly affects money market rates on impact and then evolves along the yield curve, whereby the forecast error variances of yields with longer maturities increase considerably with longer horizons. In particular, the recovered ECB signal explains 68% of the common variation of the EU's interest rates on impact and more than 71% of the same variation in the long-run. Moreover, a robustness check of the yield curve effects of the ECB-surprises confirmed the macroeconomic view of the ECB as controlling the short end of the term structure of interest rates in the euro area.

The results further revealed that different financial market segments in the NMS have attained different levels of convergence. The NMS' interest rates in the short-term market segments react more weakly (in a statistically significant manner) to the ECB's operations (on average -12%) as compared to the euro area, whereas their long-term government bond yields' responses to an ECB impulse range from +14% to +25%. A possible explanation might be that the NMS still face the challenge of accomplishing their domestic goals of economic development and market-oriented reform which implies an individual monetary policy for each NMS that differs from that applied by the ECB. In contrast, the convergence of the other-EU countries is well advanced in all financial market segments.

Appendix A: Determining the dynamic properties of common factors

Since only the space spanned by the factors can be estimated and linear combination of I(0) and I(1) factors can remain I(1), Bai and Ng (2004) propose the following algorithm to determine the dynamic properties of the common factors.

Given the model set-up:

1. Let $\tilde{F}_t$ denote the demeaned[8] estimated common factors $\hat{F}_t$;

2. Start with $m = r$ and rotate $\tilde{F}_t$ by $\hat{\beta}$, where $\hat{\beta}$ is a matrix of m eigenvectors associated with the m largest eigenvalues of $\frac{1}{T^2}\sum_{t=2}^{T}\tilde{F}_t\tilde{F}_t'$ - i.e. $\dot{F}_t = \hat{\beta}'\tilde{F}_t$ is a vector of common stochastic trends;

3. Define the statistic $MQ_c(m) = T[\hat{\omega}^c(m) - 1]$ according to a) and $MQ_f(m) = T[\hat{\omega}^f(m) - 1]$ according to b) with critical values for both test statistics given in Bai and Ng (2004):

   (a) i. Define the covariance matrix $\hat{\mathcal{S}} = \sum_{j=1}^{J} K(j)\left(\frac{1}{T}\sum_{t=2}^{T}\hat{\xi}_{t-j}\hat{\xi}_t\right)$, where $K(j)$ is the Bartlett kernel with $J = 4\text{ceil}\left(\frac{\min(N,T)}{100}\right)^{1/4}$ and $\hat{\xi}_t$ is a residual-vector of a first-order VAR in $\dot{F}_t$;

   ii. Calculate $\hat{\omega}_c(m)$ as the smallest eigenvalue of:
   $\hat{\Phi}_c(m) = 0.5\left[\sum_{t=2}^{T}(\dot{F}_t\dot{F}_{t-1}' + \dot{F}_{t-1}\dot{F}_t') + T(\hat{\mathcal{S}} + \hat{\mathcal{S}}')\right]\left(\sum_{t=2}^{T}\dot{F}_t\dot{F}_{t-1}'\right)^{-1}$;

   (b) i. For p fixed that does not depend on N or T: Estimate a VAR(p) in $\Delta\dot{F}_t$ to obtain $\hat{\Gamma}(L) = I_m - \hat{\Gamma}_1 L - ... - \hat{\Gamma}_p L^p$ and define $\dot{f}_t = \hat{\Gamma}(L)\dot{F}_t$;

   ii. Calculate $\hat{\omega}_f(m)$ as the smallest eigenvalue of:
   $\hat{\Phi}_f(m) = 0.5\left[\sum_{t=2}^{T}(\dot{f}_t\dot{f}_{t-1}' + \dot{f}_{t-1}\dot{f}_t')\right]\left(\dot{f}_{t-1} + \dot{f}_{t-1}'\right)^{-1}$;

4. If $H_0 : m = r$ is rejected, set $m = m - 1$ and return to 2). If $H_0 : m = q$ cannot be rejected, set $r_1 = m$ and stop.

[8] Note that if the data are considered to consist of a constant and a linear trend, $\tilde{F}_t$ denotes the residuals from a regression of $\hat{F}_t$ on a constant and a linear trend.

Note that a factor rotation matrix $\hat{G}$ can be defined as $\hat{G} = [\hat{\beta}', \hat{\beta}'_{\perp}]'$ whereby the $(r \times r_1)$ vector $\hat{\beta}$ is given as in Step 2 and where $\hat{\beta}_{\perp}$ is the $(r \times r_0)$ orthogonal complement to $\hat{\beta}$. With this choice of $\hat{G}$, the space of the common factors can be rotated such that the first r_1 elements of $\hat{G}\hat{F}_t$ are I(1) and the remaining r_0 factors are I(0).

Appendix B: Data

Money market rates	
Overnight rate	euro area (EONIA), SE, UK, CZ, HU, LV, LT, PO, SK
1-month rate	euro area, DK, SE, UK, CZ, EE, HU, LV, LT, PO, SK
3-months rate	euro area, DK, SE, UK, CZ, EE, HU, LV, LT, PO, SK
1-year rate	euro area, DK, SE, UK, CZ, EE, LV, LT, PO, SK
Government bond yields	
2-years yield	euro area, AU, BE, FR, DE, IT, NL, ES, PT, DK, SE, UK
3-years yield	euro area, AU, BE, FI, FR, DE, IT, NL, ES, PT, DK, SE, UK
5-years yield	euro area, AU, BE, FI, FR, DE, IE, IT, NL, ES, PT, DK, SE, UK
7-years yield	euro area, AU, BE, FR, DE, IE, IT, NL, ES, PT, DK, SE, UK
10-years yield	euro area, AU, BE, FI, FR, DE, IE, IT, NL, ES, PT, DK, SE, UK, CZ, HU, PO
20/30-years yield	euro area, AU, BE, FR, DE, IE, IT, NL, ES
Exchange rates	
euro per individual currency	DK, SE, UK, CZ, EE, HU, LV, LT, PO, SK

Source: Datastream.

Country abbreviations: AU: Austria, BE: Belgium, FI: Finland, FR: France, DE: Germany, IE: Ireland, IT: Italy, LU: Luxembourg, NL: The Netherlands, ES: Spain, PT: Portugal, DK: Denmark, SE: Sweden, UK: United Kingdom, CZ: Czech Republic, EE: Estonia, HU: Hungary, LV: Latvia, LT: Lithuania, PO: Poland, SK: Slovakia.

Treatment

All interest rates and yields are converted into euros. That is, from the viewpoint of a risk-neutral euro area investor, all the interest returns are calculated as

$$X_{i,t} = X_{ci,t} + \ln(S_t) - \ln(E(S_{t+1})),$$

where $X_{ci,t}$ denotes the non-eurozone interest rate or yield i of country c, S_t is the euro exchange rate per individual currency, and $E(S_{t+1})$ is set to its realized value at $t+1$ because forward currency rates are not available for all of the NMS. Following Stock and Watson (2005), the data are further adjusted for outliers. The anomaly adjustment is applied to the first differentiated data and involves replacing data-points that have an absolute median deviation larger than six times the interquartile-range with the median value of the preceding five data-points. For determining the number of factors and their estimation, the first differenced data is standardized to effectively downweight volatile series.

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