The forecasting power of international yield curve linkages*

Michele Modugno[a,b] and Kleopatra Nikolaou[a]

a: European Central Bank

b: Université Libre de Bruxelles

December 2007

Abstract

We investigate whether international linkages in interest rates help forecast domestic yield curves out-of-sample. We propose a novel international setting to forecast yield curves, based on dynamic factor models, the EM algorithm and the Kalman filter. We apply this methodology on three major countries, the US, Germany and the UK. We allow information from foreign yield curves to enrich the information set of the domestic yield curve. Each domestic yield curve is summarised by three factors (level, slope and curvature). Our results show that the international model outperforms the purely domestic model in forecasting the yield-curve of countries with lagging dependency patters. Intuitively, our results reveal a dynamic dependency of the German yield curve on the US and the UK and, to a lesser extent, of the UK yield curve to the US and Germany. The US yield curve appears detached from transatlantic developments.

JEL classification: F31.

Keywords: Yield curve forecast; Dynamic factor model; EM algorithm, International linkages.

*__Acknowledgments:__ This paper was partly written while Kleopatra Nikolaou and Michele Modugno were at the European Central Bank. The authors are indebted for useful conversations and constructive comments to Laura Coroneo, Domenico Giannone, Michele Lenza, Lucio Sarno, Ilias Tsiakas and David Veredas. The authors alone are responsible for any errors that may remain and for the views expressed in the paper.

1 Introduction

Forecasting the yield curve has always attracted a considerable amount of attention among academics, policymakers and practitioners due to its broad impact on all classes of economic agents and all forms of financial and economic activity. The relevant literature typically uses domestic (latent) factor models, which summarise the information from observable yields in a few yield curve factors (Dai and Singleton, 2000; Ang and Piazzesi, 2003; Diebold and Li, 2006). Nevertheless, fluctuations among certain yields and macro variables are becoming increasingly synchronised across countries, in line with intensifying global integration (see references below). This could imply dynamic dependencies also among yield curves of various countries, and thereby lead to a fundamental, yet unexplored question: Can information from foreign yield curves help improve domestic yield curve forecasts? This paper is a first attempt to answer the above question, thereby extending the yield curve forecast literature towards the international direction.

Our approach feeds from and extends previous anecdotal empirical evidence on international dependency patterns. Dewachter and Maes (2001), Diebold et al. (2006) and Pérignon et al. (2007) explore contemporaneous dynamic interdependencies of yield curves across countries and demonstrate, among others, the existence of common factor(s) which explain a significant part of yield developments in individual countries. Alongside the yield curve literature, a related strand of research focused on revealing causality linkages on individual yields across major countries (Frankel et al., 2004; Chinn and Frankel, 2005; Wang et al., 2007). This strand of literature uses a variety of in-sample fit techniques[1] to provide evidence of strong international dependencies among interest rates, with the direction of causality typically running from the US to the rest of the world. Bidirectional causalities with other major countries such as Germany and the UK are broadly unclear. Building on this evidence, we asses whether such linkages are strong enough to help us forecast the whole yield curve out of sample.

We propose, estimate and forecast (out-of-sample) a novel dynamic factor model for the yield curve, where information from foreign yield curves can be introduced in domestic yield curve forecasts. We want to compare the forecast accuracy of our international model versus a purely domestic model. In order to do that, we first summarise the information contained in each domestic yield curve into three country-specific dynamic factors. We then exploit the dynamic structure of the factors to produce forecasts. Domestic forecasts will be produced purely from the domestic factors, whereas international forecasts will be produced by the interaction of domestic factors with foreign factors in a vector autoregression setting.

[1] The exception is Wang et al. (2007), who perform out-of-sample Granger causality tests for individual rates.

As a consequence, under the international model domestic factor forecasts are enriched with information from foreign factors. Finally, we reconstruct future yields from the factor forecasts and compare the forecasts under the domestic and the international approach. In that sense, the international model nests the domestic model and allows direct forecast comparisons.

Our estimation method employs Maximum Likelihood (ML) techniques based on the EM algorithm and the Kalman filter (Doz et al., 2006; Coroneo et al., 2007) in order to effectively cope with two main estimation challenges . First, we identify the factors driving the yield curve as level (L), slope (S) and curvature (C) according to the methodology of Diebold and Li (2006)[2]. This technique allows the generalisation of our modelling methods and our forecast results to the whole yield curve[3]. Second, we use an extensive data set consisting of a large cross-section of yields for three countries (US, Germany and UK). Previous yield curve techniques involved two-step procedures, where the L, S and C factors of each country were typically extracted outside the maximisation process, mainly because the econometric tools being used were prohibiting the use of estimation methods with embedded restrictions for a large cross-section of data (Diebold et al. 2006). Our estimation method sidesteps these problems and allows us to directly estimate our yield curve factors from multi-country information sets, while imposing the necessary identifying restrictions (Coroneo et al., 2007).

Our results provide ample support for the international model. In fact, we show that international yield curve linkages can significantly improve forecasts of countries that appear more depended on international information (in a statistical sense). On the contrary, more independent countries in the international setting, therefore not so much influenced by international information, appear not to benefit largely from the international model. More precisely, we find that German yield curve forecasts are particularly improved by including information from the US and the UK, thus suggesting a dynamic dependency of Germany on these two countries. The relationship appears unidirectional for the US, where the domestic model appears to be the best, thereby confirming its leading role. Finally, the UK is partly influenced by international linkages, mainly at longer forecast horizons. Our results suggest clear dependency patterns among the countries considered, in line with previous anecdotal empirical evidence and generalise these findings for the whole yield curve. Overall, our results support a more outward-looking perspective in modelling financial variables.

[2] The Diebold and Li (2006) model is flexible enough to capture the changing shape of the yield curve, yet it is parsimonous and easy to estimate. This is especially important whithin our context, where the multiplicity of countries puts further strains on the estimation procedure.

[3] This is possible, since the imposed restrictions adequately summarise all possible maturities contained in a yield curve. Should the coefficients not be identified, then we would not be able to generalise our results to all moaturies, observed and unobserved, therefore we could not talk about the "yield-curve".

The paper is structured as follows. Section 2 discusses the potential sources of interest rate linkages in the literature, while also providing a more detailed view of the relevant empirical literature. Section 3 presents the factor model specifications used in this paper and elaborates on the estimation and forecast methodologies being used. Section 4 gives an overview of the data used and their sources. Section 5 analyses the estimation results, and Section 6 summarises.

2 International linkages in interest rates

2.1 Driving forces of international interest rate linkages

Little is known about the theoretical foundation of international interest rate linkages, relative to the broad empirical evidence of their existence (see below). Nevertheless, the case of international linkages in interest rates comes intuitively if one considers the growing evidence on increased synchronised fluctuations in major economic variables. Koze et al. (2004) provide evidence of global forces driving the business cycles of different countries contemporaneously, whereas Giannone and Reichlin (2005) provide evidence of lagged dependencies between the business cycles of US and Germany (with the US leading Germany). At the same time, Mojon and Ciccareli (2005) empirically support the notion of global inflation. In practice, strong comovements in output and inflation could result to international linkages in interest rates of different countries and more specifically in the yield curve linkages, since these macroeconomic variables are highly correlated with the factors driving interest rates of various maturities (Ang and Piazzesi, 2003; Diebold et al., 2006).

Looking at the literature, Frankel et al. (2004) identify the main factors driving international interest rate linkages as the degree of financial integration of the domestic economy into world markets, the degree of real integration, and the nature of global shocks. Globalisation forces especially, enjoy a prominent role in driving developments in inflation and interest rates across countries (Borio and Filardo, 2007; Rogoff, 2006). Although the above claims are valid, globalisation should most probably be viewed as determining the importance of a global factor, rather than being itself a factor (Nikolaou, 2007). On a different footing, Chinn and Frankel (2005) attempt to decompose interest rate differentials into a country premium (determined by such factors as capital controls, transaction costs, imperfect information, default risk, tax differentials, and risk of future capital controls) and a foreign exchange risk premium (determined by expected depreciation plus the exchange risk premium), in order to motivate theoretical linkages in interest rates. Nikolaou (2007) further extends this line of thinking and suggests that international linkages depend on six factors, by decomposing interest rate differentials into a real and nominal part, a riskless and risky part. She suggests as global factors the convergence between countries of the real rates and inflation rates and their respective risk premia, and the evolution of exchange rate changes and their respective risk premia. She further suggests that globalisation is the force determining convergence rates and stabilisation of exchange rates.

2.2 Empirical evidence of international interest rate linkages

In the empirical front, many studies looked at the effects of economic and financial integration on interest rates. A major strand focused on certain maturities (typically long or short) and addressed specific questions relevant to the maturities examined. For example, Dungey et al. (2000) rationalise international portfolio diversification by decomposing international interest rate differentials of 10 year bonds into national and global factors. They suggest the construction of an optimal portfolio, based on the global factor, which can outperform a simple equally weighted portfolio. On the short maturity front, an important strand investigates monetary policy independence in a multi-country environment. They reasoning is that sufficiently large or isolated countries, could more easily pursue independent monetary policy. On the other hand, in a globalised environment domestic economic variables could be driven by global forces. In that case they may be less responsive to domestic policies or influences from domestic causes. That would induce authorities to adopt a less independent, more outward looking perspective in decision making (Borio and Filardo, 2006).

Following this line, Chin and Frankel (2005) employed Granger causality tests on short (and long) term rates, taking into account the existence of possible long-run relationships in cross-country interest rates. They provide evidence of strong international dependency structures and report bidirectional linkages, although the US and in some cases Germany appear to be more independent. Frankel et al. (2004) adopt a panel analysis to test whether sensitivity of domestic money market interest rates to international interest rates is affected by the exchange rate regime. They find that over the last decade all exchange rate regimes exhibit high sensitivity of local interest rates to international ones. They also find that the US, Germany and Japan seem to be the only countries in their panel that can choose their own interest rates in the long run. Wang et al. (2007) follow a similar approach, to examine linkages in Eurocurrency rate. Their out-of-sample causality test complements an extensive previous literature on the subject. They find that the German eurocurrency rate had a strong global player status before the introduction of the euro. Nevertheless, after the introduction of the euro, the role of the US rate in affecting euro-zone currency interest rates increased. His results also suggest strong international linkages and multiple directions of global interactions.

Shifting our attention to the international yield-curve literature, although sparse, it clearly supports the idea of global factors driving the yield curve contemporaneously (lagged dependency patterns remain broadly unexplored and not clearly demonstrated). The number and interpretation of these factors varies, but plausible interpretations appear to link international factors to global macroeconomic variables. Dewachter and Maes (2001) propose and estimate a model to account for the dynamic interdependencies of term structure of interest rates across two countries, the US and the UK, using an affine term structure model. They achieve this by allowing the short term interest rate to be driven by both local and global international factors and by linking the pricing kernels of the two countries via exchange rate movements. They suggest that the international factors correspond to international level effects, and the local factors to national slope effects. Diebold et al. (2006) extend the NS yield curve model to four major countries. They use dynamic factor analysis to estimate the domestic (L and S) yield factors of each country and then group these factors to extract global (L and S) factors. They provide evidence that global yield factors explain significant fractions of yield curve dynamics across countries. They also show that the global share of bond yield variation is smallest for the US across all maturities, consistent with relative independence of the US market. They suggest that the level factor relate to the global inflation and the slope factor the global business cycle. Other related studies on the term structure use static factor analysis. Driessen et al. 2003 find evidence in favor of five common factors, however, Pérignon et al., 2007, specifically allowed for local factors and report a single common factor, associated most notably with changes in the level of domestic term structures.

How does our paper fit into this literature? Our paper extends the above literature in two ways. First it is the first attempt to forecast the yield curve using international information, to the best of the author's knowledge. Second, we allow for both contemporaneous and lagged dependency patterns of the yield curve among different countries, thus generalising previous evidence for the whole yield curve. At the same time, we test the strength of such linkages in a very robust way, i.e. by means of an out-of-sample forecast exercise. Our methodology is different from the previous ones in that our international model needs not directly extract global factors, rather it tests their existence implicitly, by allowing the interplay of domestic yield factors of various countries to add information to the domestic forecast model. Our results, consistent with previous literature, reveal a dynamic dependency of the German yield curve on the US and the UK and, to a lesser extent, of the UK yield curve to the US and Germany. The US yield curve appears detached from transatlantic developments.

3 Methodology

We use a dynamic factor model and maximum likelihood estimation techniques based on the EM algorithm to estimate and forecast out-of-sample the yield curve in domestic and international settings. We summarise the yield curve of each country into three dynamic factors and we forecast the yields by forecasting the factors. The domestic setting allows only own factor information (single autoregression), whereas the international setting allows information from all countries factors (vector autoregression). In this way, the international framework is a straightforward extension of the domestic and the exercise can be seen as an out-of-sample dependency test. Our estimation window starts from January 1986 to December 1999 and our evaluation window extends from January 2000 to May 2006. We use as a benchmark a simple random walk model (RW) and compare the relative forecasting power of each model against the benchmark.

Overall, we compare the domestic with the international model in two formulations: The *domestic yields-only model*, where the L, S and C factors of each country are extracted purely from domestic yields and their forecasts use own information only and the *international yields-only model*, where the L, S and C factors of each country are extracted purely from domestic yields but their forecasts use information from all countries. We structure the models in such way so that the international model nests the domestic one, thereby providing direct comparison between the two formulations.

We explore the dynamic dependencies between Germany, the US and the UK. German yields are dynamically dependent on international yields, if including information from the latter improves German forecasts. The link is bidirectional if German information also helps forecast foreign yields. The same principle holds for the other countries. In that sense, our methodology acts as an out-of-sample dependency test on the whole term structure of interest rates, thus providing generalised evidence on dynamic dependencies across countries.

Finally, the use of ML techniques combined with the EM Algorithm and the Kalman Filter is the ideal methodology for our approach. It is the only one that allows us to consistently estimate large cross sections (Doz et al.,2006), while at the same time effectively deal with restrictions in the factor loadings (Coroneo et al., 2007). We can, therefore, exploit information from an extended data set, while at the same time generalise our results to the whole yield curve, in a simple one-step estimation process. We thereby sidestep estimation issues which were barring similar routes of research in this field.

3.1 Modelling the yield curve using a dynamic factor model

Dynamic factor models capture the common features (correlations) among economic series within unobserved common factors. In contrast to static factor models (i.e. principal components), dynamic factor models allow the underlying factors to evolve dynamically, so they have the advantage of measuring contemporaneous and temporal comovements among the variables. Such models were originally proposed by Stock and Watson (2002 a, b) and advanced by Forni et al. (2000, 2002, 2005).

3.2 A domestic factor model for the yield curve

Nelson and Siegel (1987) and Diebold and Li (2006) have customised dynamic factor models on the yield curve. Diebold and Li (2006) interpret the parsimonious yield curve model of Nelson and Siegel (1987) as a three latent factor model, where factors are identified as L, S and C by imposing appropriate restrictions on the factor loadings. Namely,

$$y_t(m) = L_t + S_t \left(\frac{1 - e^{-\lambda m}}{\lambda m} \right) + C_t \left(\frac{1 - e^{-\lambda m}}{\lambda m} - e^{-\lambda m} \right) + \varepsilon_{t(m)}, \tag{1}$$

the yield of maturity m at time t, $y_t(m)$, depends on the factors L, S, C and on $\varepsilon_{t(m)}$, the residual or pricing error. The factors are identified by setting the predetermined loadings $[1, \frac{1-e^{-\lambda m}}{\lambda m}, \frac{1-e^{-\lambda m}}{\lambda m} - e^{-\lambda m}]$. These loadings depend on maturities (m) and the λ parameter. This parameter governs the exponential decay rate of the yield curve at each maturity. Diebold and Li (2006) keep the λ parameter constant at 0.069 over time in order to reduce the volatility of the factors, thus making the model more predictable. In effect they consider the following matrix form:

$$Y_t = \Gamma' F_t + \varepsilon_t \tag{2}$$

or

$$Y_t = \begin{bmatrix} \Gamma_L & \Gamma_S & \Gamma_C \end{bmatrix} * \begin{bmatrix} L_t \\ S_t \\ C_t \end{bmatrix} + \varepsilon_t , \tag{3}$$

where Y_t is a vector containing the cross-section of observed yields at time t, i.e. the observed yields of maturity m at time t. Γ is a vector containing the predetermined yield-curve factor loadings [Γ_L, Γ_S, Γ_C] of Diebold and Li, that is $[1, \frac{1-e^{-\lambda m}}{\lambda m}, \frac{1-e^{-\lambda m}}{\lambda m} - e^{-\lambda m}]$ respectively for every m, at time t. In their turn, the yield curve factor loadings [L_t, S_t, C_t] at time t are contained in vector F_t. The yield-factors are modeled as separate first-order autoregressive or AR(1) processes and forecasts of the factors are being used to generate forecasts of the yields. This formulation outperforms RW forecasts of the US yield curve at longer forecast horizons (12 steps ahead) for almost all maturities involved. We use this formulation in our model as our benchmark *domestic yields-only model.*

3.3 An international factor model for the yield curve

Our methodology extends the line of Diebold and Li (2006) to the international setting, resulting to the *international yields-only model.* In this case, we consider a vector Y_t containing information on the yields of more than one country (in our case three countries, Germany, US and the UK). The main idea remains that we summarise the information from each country's yield curve into three country-specific yield factors contained in vector F_t, and a country-specific yield pricing error $\varepsilon^c_{t,Y}$. The factors are identified as L^c_t, S^c_t and C^c_t (where $c = \{GE, US, UK\}$) by imposing the predetermined factor loadings on the yield curve factors of each country.

In a general form, our model looks like:

$$Y_t = \Gamma' F_t + \varepsilon_t, \tag{4}$$

or

$$\begin{bmatrix} Y^{GE}_t \\ Y^{US}_t \\ Y^{UK}_t \end{bmatrix} = \begin{bmatrix} \Gamma_L & 0 & 0 & \Gamma_S & 0 & 0 & \Gamma_C & 0 & 0 \\ 0 & \Gamma_L & 0 & 0 & \Gamma_S & 0 & 0 & \Gamma_C & 0 \\ 0 & 0 & \Gamma_L & 0 & 0 & \Gamma_S & 0 & 0 & \Gamma_C \end{bmatrix} * \begin{bmatrix} L^{GE}_t \\ L^{US}_t \\ L^{UK}_t \\ S^{GE}_t \\ S^{US}_t \\ S^{UK}_t \\ C^{GE}_t \\ C^{US}_t \\ C^{UK}_t \end{bmatrix} + \begin{bmatrix} \varepsilon^{GE}_t \\ \varepsilon^{US}_t \\ \varepsilon^{UK}_t \end{bmatrix}, \tag{5}$$

where now Y_t is a vector containing the observed cross-section of yields for each country c at time t, summarised as $[Y^{GE}_t, Y^{US}_t, Y^{UK}_t]$. Γ is a block-diagonal matrix containing the yield curve predetermined loadings ($[\Gamma_L,\ \Gamma_S,\ \Gamma_C]$) for the yield factors of each country $[L^c_t, S^c_t, C^c_t]$ respectively. The latter are contained in vector F_t. Finally, ε_t contains the country-specific, yield curve pricing errors $[\varepsilon^{GE}_t, \varepsilon^{US}_t, \varepsilon^{UK}_t]$, which are assumed to be zero mean, contemporaneously uncorrelated, normal random variables. In this setting we need to estimate only the factors contained in F. It is important to stress that the factors estimated in F, are still domestic factors and the only difference from the domestic model, up until this point is that the estimation involves more than one countries contemporaneously.

It is the transition equation that makes the distinction between the domestic and the international model clear. This is achieved by modelling in a vector autoregressive (VAR) framework the same class of factors across countries, thereby allowing interactions across factors of different countries. More specifically, for the yields-only (macro-yields) model, the factors contained in F_t are modelled separately as a first-order vector autoregressive or VAR(1) process. The transition equation for each of the factors across countries, is

$$F_t^{\varphi} = A^{\varphi} F_{t-1}^{\varphi} + w_t^{\varphi}, \tag{6}$$

where φ corresponds to $L, S,\ C$, i.e. $\varphi = \{L, S, C\}$. A^{φ} contains the autoregressive coefficients that measure the persistence of the factors. It is a full matrix, thereby allowing international interactions among the factors of each country. Although, we allow international spill-overs among countries we do not do so among the factors themselves. For example, L^{US} (S^{US}, C^{US}) can affect only the L^{GE} (S^{GE}, C^{GE}) and vice-versa. This is a plausible assumption, given that the correlation among the same class of factors of different countries is high, whereas the correlation among different classes of factors is low (Diebold et al., 2006). Finally, w_t is the innovation vector with components that are zero mean, contemporaneously uncorrelated normal random variables, orthogonal to the common factors, $E(F_t\ w_t') = 0$ and the idiosyncratic component $E(\varepsilon_t\ w_t') = 0$.

For exposition purposes we fully demonstrate the dynamics of the level factor, L_t, across countries:

$$\begin{bmatrix} L_t^{GE} \\ L_t^{US} \\ L_t^{UK} \end{bmatrix} = \left[A^L\right] * \begin{bmatrix} L_{t-1}^{GE} \\ L_{t-1}^{US} \\ L_{t-1}^{UK} \end{bmatrix} + \begin{bmatrix} w_{t,GE}^L \\ w_{t,US}^L \\ w_{t,UK}^L \end{bmatrix}. \tag{7}$$

In sum, the structure of our domestic versus the international model specification now becomes clear. The domestic model uses purely domestic information, since it contain yields only from country c in the Y_t vector. For example, for c=GE, the domestic model for Germany will only contain the cross section of German yields in the Y_t vector. L^{GE}, S^{GE}, C^{GE} will summarise information from the domestic Y_t vector and evolve without receiving feedback from each other, or from foreign sources. In the international model the Y_t vector contains yields from all c countries. In that case, the country-specific $L^c, S^c,\ C^c$ factors summarise the yield curve information of their respective countries, but international feedback across the same class of factors will be allowed to form their evolution. Should international information add further value, the evolution of the factors will be different under the international model. It is therefore apparent that the international model is an extension of the domestic model when it comes to the dynamic evolution of the yield curve factors. In this sense, it can be seen as an out-of-sample dependency test, since information from other countries helps forecast the domestic yield curve out-of-sample.

3.4 Forecasting the yield curve

This section describes the procedure we use to forecast the yield curve based on the domestic and the international model. Our benchmark is a naive RW forecast, where the best forecast for a given yield today is yesterday's value. We employ a recursive forecast exercise on each model, which can be described as follows: We start with a sub-sample of our data (from January 1986 to December 1999) and apply the EM algorithm to extract the underlying factors and estimate the parameters. Based on these estimates we produce out-of-sample forecasts, one, six and twelve steps ahead ($h = 1, 6, 12$), using the iterative forecast method, with:

$$\widehat{F}_{t+h} = (A^{\varphi})^h F_t, \tag{4.3}$$

where $(A^{\varphi})^h$ is the A^{φ} matrix raised to the power h. Given the forecast of the factors it is now easy to revert the procedure in Section 2.3 and derive the forecast of the whole yield curve as

$$\widehat{Y}_{t+h} = \Gamma' \widehat{F}_{t+h}. \tag{4.3}$$

To continue, we compare the forecasted value with the actual value of the yield and calculate the squared forecast error (SFE). We then include one more observation (actual value) in our sample and start again the extraction, estimation, forecast and evaluation of the new sample period. The repetitions last until we reach the full length of our sample, by which time we have a series of SFE. We take the mean of the SFE (MSFE) series as a measure of the model's forecasting accuracy. The lower the MSFE measure, the more accurate the forecast.

This procedure is followed both for the domestic model and the international model. Our focus rests entirely on comparing these two models, however we also introduce naive RW forecasts for the interest rate series, where $\widehat{Y}_{t+h} = Y_t$ for all h, as a standard benchmark in this literature. We, therefore, display the forecasting performance of the domestic and international model relative to the RW forecast. The lower the MSFE ratio between the model-based forecast and the RW, the higher the forecasting accuracy. A ratio of unity (1) indicates equal forecasting power between the chosen model and the RW model. A ratio of less than unity suggests that the chosen model's forecast outperforms the RW forecast.

To formalise our forecasting results, we apply White's (2000) "reality check". This is a test of superior forecast accuracy, where a benchmark model can be tested among a number of potential alternative models. The null hypothesis is that none of the alternative specification has superior forecast accuracy than the benchmark. We implement the model in the following fashion: First, we take the international model as a benchmark versus the domestic and RW models. Should we accept the null, it means that none of the alternative models has superior forecast accuracy. However, to establish that our model is superior, we cross-check following Hördahl et al., 2005 by running pairwise bootstrap tests. In these tests we alternate the benchmark between the RW and the domestic model and run the tests for each benchmark vs the international model. Should we reject the null in both cases, it means that the international is indeed the best forecast.

4 Data

We use an extensive data set, which consists of monthly zero-coupon bond yield series for three major countries, Germany, the US and the UK for a period spanning a common sample from January 1986 to May 2006. Bond yield maturities range from 1 year to 10 years (i.e. $m = 1$ to 10 years). Our source is the Bank for International Settlements (BIS), which accumulates zero-coupon data for a large panel of countries, provided by the respective central banks.

5 Results

In this section we present the statistical results of our forecast exercise for the different model specifications and interpret the findings in the light of international dependencies among the countries considered. The statistical findings are summarised in Tables 1 to 6. Tables 1, 2 and 3 present our forecast results for Germany, the US and the UK respectively. Tables 4 to 6 present the bootstrap tests for superior forecasting accuracy between the international and the domestic model for each country.

5.1 Analysis

Comparing the international with the domestic model, our results suggest clear forecasting patterns for each country: The international model proves to be a very good forecasting tool for countries dependent on international information (in a statistical sense). Looking separately at each country, we observe the following:

For the case of Germany, the international model beats the domestic model. This is a general result that holds for all maturities, all forecast horizons and all model specifications. The international model (All) produces consistently lower MSFE ratios (Table 1) which tend to decline on average with longer forecast horizons and, in most cases, also with maturity (up to 9 years). These readings are confirmed by the bootstrap tests (Table 4). The White test shows that the null of no other superior model is generally accepted (Benchmark: All), whereas the pairwise bootstrap test confirms that the alternative international forecast is indeed superior than the domestic one (Benchmark: GE). Moreover, we find that the international model has superior forecasting accuracy compared to the RW for longer forecast horizons whereas for short forecast horizons the two models perform equally well (Benchmark RW).

We find the opposite results for the US. In fact, adding information from Germany and the UK to the domestic US model does not improve forecasting power in a statistically significant sense (yields-only model). MSFE appear to be very close to unity for almost all model specifications, horizons and maturities, suggesting that the different models have equal forecasting accuracy (Table 4). Indeed, evidence from the bootstrap tests (Table 5) confirms this result (i.e. the null is not rejected in any case).

The results on the UK appear someway in between German and US results. Adding international information appears to significantly improve forecasts mainly at long horizons (12 steps ahead). In that case MSFE drop below unity (Table3), in what appears to be a statistically significant drop (the pairwise tests in Table 6 suggest that the alternative international model is superior, whereas the white's test does not reject the null of no other model's superiority).

5.2 Interpretation

Our fundamental question, i.e. wether the inclusion of international information helps improve the predictability of a domestic series, can be viewed as an out-of-sample Granger causality test[4]. In that light, out results reveal dependency patterns with clear directions. Germany and the US appear at the two ends of the spectrum, with the first profiting greatly from international information while the second being sufficient on domestic information. The UK appears to lie mid-way. In other words, they suggest a more independent role for the US in the international environment (i.e. causality linkages among other countries and the US are unidirectional). Germany appears to be particularly dependent on information coming from foreign sources (one way causality with the US and UK), while the UK appears dependent to a much smaller extent (two-way causality with Germany and one-way with the US). Our results generalise previous literature results on international linkages in interest rates (Frankel et al.,2004; Chinn and Frankel, 2005; Belke and Gross, 2005), further supporting a leading role for the US and the existence

[4]Out-of-sample Granger causality tests are more powerful and robust tests than the respective in-sample ones, since they convey the maximum amount of information for testing the Granger causality hypothesis (Granger, 1969; Ashley et al. 1980) and is, therefore, closer to the spirit of Granger's (1969) true definition of causality.

of lagging dependency patterns between the US and Germany.

Finally it should be stressed that the above dependency patterns are established in a statistical sense only. This has two implications: First, it is not clear if such linkages are economically significant, i.e. if trading gains can be established based on our forecasts. This is an analysis that would need to involve more inputs (such as establishing arbitrage opportunities and including trading costs and restrictions to replicate trading strategies). Second, the channels generating these linkages, are not exposed, albeit clearly exploited: In this study we document dependency patterns in the yield curves of different countries, strong enough to help us in forecasting. However, we do not try to identify the cause of such linkages. For example, such patterns can be generated because different countries might have different resistance levels to various global shocks, thereby reacting to them at a later stage. In that case, even independent movements can result to similar yield-curve patterns. A theoretical model detailing the channels and mechanisms linking economies remains an open challenge for future research.

6 Conclusion

This paper presents a novel approach and methodology to forecast the yield curve by exploiting international linkages and dependency patterns among yield curves of different countries, against a background of increasing global economic and financial integration. Our motivation stems from related literature establishing contemporaneous and inter-temporal links in the yields of different countries. We, therefore, adopt the prior that augmenting a purely domestic information set with international information could improve forecasting power. We test our conjecture by extending the standard domestic yield curve models towards the international dimension. More specifically, we use a three country setting, where each country has its own yield curve, summarised into (domestic) level, slope and curvature factors. International information comes into play in the forecasting phase. There, information from foreign yield curves is allowed to enter in the forecast of the domestic yield curve. This is the international counterpart to the domestic forecast, where only domestic information feeds into the forecast of the domestic yield curve.

We employ a dynamic factor model and ML estimation techniques based on the EM algorithm and the Kalman filter to estimate and forecast the different model specifications. The combination of the EM algorithm and the Kalman filter allows us to efficiently estimate the model using a large number of variables and to successfully restrict factor loadings to identify yield factors as L, S and C. This methodology improves the competitive edge of our paper, since it allows us to generalise our results to the whole yield curve, while extending our data set and methodology to more than one countries in a compatible way between the two models (domestic and international).

Our results suggest that international linkages can help improve yield curve forecasts especially for countries with lagging dependency patterns. More precisely, the international model works particularly well for the German case. In the UK, international information from Germany and the US helps at longer forecast horizons, whereas the US appears to be impervious to transatlantic developments. Such results suggest a clearly leading role for the whole US term structure and a lagging dependency pattern for Germany. Our results are compatible with previous anecdotal evidence on interest rates, thereby generalising such evidence to the whole yield curve.

Overall, this paper presents a novel methodology to address a topical question of whether adding international information can help forecast the domestic yield curve in a simple but holistic way. The originality of this paper lies mainly on the question addressed but also on the methodology proposed to address and on state-of-the-art econometric methodologies, which ensure efficiency and flexibility. Our results suggest that international linkages across countries can affect major financial variables and, therefore, provide further support to anecdotal evidence suggesting that a more outward-looking perspective in policy making is, perhaps, warranted.

References

[1] Ang, A. and M. Piazzesi (2003), "A No-Arbitrage Vector Autoregression of Term Structure Dynamics and Macroeconomic and Latent Variables," Journal of Monetary Economics, 50(4), pp. 745-787.

[2] Borio, C. and A. Filardo (2006), "Globalisation and Inflation: New Cross-Country Evidence on the Global Determinants of Domestic inflation," BIS, *mimeo.*

[3] Belke, A. and D. Gros, 2005, "Asymmetries in Trans-Atlantic Monetary Policy Making: Does the ECB Follow the Fed?", Journal of Common Market Studies, 43(5), pp. 921-46.

[4] Chinn, M. and J. Frankel (2005), "The Euro Area and World Interest Rates," Santa Cruz Department of Economics, Working Paper Series, 1031.

[5] Coroneo, L., D. Giannone and M. Modugno (2007), "Forecasting the term structure of interests rates using a large panel of macroeconomic data," *mimeo.*

[6] Dai, Q. and K. Singleton, 2002, "Expectation Puzzles, Time-varying Risk Premia, and Affine Models of the Term Structure," Journal of Financial Economics, 63, pp. 415-41.

[7] Dewachter H. and M. Konstantijn (2001), "An Admissible Affine Model for Joint Term Structure Dynamics of Interest Rates," International Economics Working Papers Series, wpie001, Katholieke Universiteit Leuven, Centrum voor Economische Studiën, International Economics.

[8] Diebold, F.X. and C. Li, 2006, "Forecasting the Term Structure of Government Bond Yields" Journal of Econometrics, 130, pp. 337-364.

[9] Diebold, F.X., G.D. Rudebusch, and S.B. Aruoba, 2006, "The Macroeconomy and the Yield Curve: A Dynamic Latent Factor Approach", Journal of Econometrics, 131, pp. 309-338.

[10] Diebold, F.X., C., Li and V.Z. Yue (2007), "Global Yield Curve Dynamics and Interactions: A Generalised Nelson-Siegel Approach," *mimeo.*

[11] Doz, C., D. Giannone and L. Reichlin (2006), "A quasi maximum likelihood approach for large approximate dynamic factor models," ECB Working Paper No 674.

[12] Favero, C., L. Niu and L. Sala (2006), "Term Structure Forecasting: No-arbitrage Restrictions vs. Information set Expansion", Working Paper.

[13] Fisher, R.W. (2005), "Globalisation and Monetary Policy," Warren and Anita Manshel Lecture in American Foreign Policy, Harvard University, 3 November.

[14] Frankel, J., S.L., Schmukler, L. Serven (2004), "Global Transmission of Interest Rates: Monetary Independence and Currency Regime," Journal of International Money and Finance, 23, pp. 701-33.

[15] Forni, M., M. Hallin, M. Lippi and L. Reichlin (2000), "The Generalized Dynamic-Factor Model: Identification And Estimation," The Review of Economics and Statistics, 82(4), pp. 540-54.

[16] Forni, M., M. Hallin, M. Lippi and L. Reichlin (2004), "The Generalized Dynamic-Factor Model: Consistency and rates," Journal of Econometrics, 2004, 119 (2), pp. 231-55.

[17] Forni, M., M. Hallin, M. Lippi and L. Reichlin (2005), "The Generalized Dynamic Factor Model: One-Sided Estimation and Forecasting," Journal of the American Statistical Association, 100, pp. 830-40.

[18] Geweke, J. (1977), "The Dynamic Factor Analysis in Economic Time-Series Models," in D.J. Aigner and A.S. Goldberger, eds., Latent Variables in Socio-Economic Models, (Amsterdam, North-Holland).

[19] Giannone, D. and L. Reichlin, 2006, "Trends and cycles in the euro area: how much heterogeneity and should we worry about it?," European Central Bank, Working Paper Series 595.

[20] Harvey, A.C. (1989), "Forecasting, Structural Time Series Models and the Kalman Filter," Cambridge, Cambridge University Press.

[21] Hashmi, A. R. and A. S. Tay (2007), "Global regional sources of risk in equity markets: Evidence from factor models with time-varying conditional skewness," Journal of International Money and Finance, 26(3), pp. 430-53. April.

[22] Hördhal, P., O. Tristani and D. Vestin (2006), "A Joint Econometric Model of Macroeconomic and Term-Structure Dynamics", Journal of Econometrics, 131(1-2), pp. 405-44.

[23] Kose, M.A., C. Otrok and C.H. Whiteman (2003), "International Business Cycles: World, Region, and Country-Specific Factors," The American Economic Review, 93(4), pp. 1216-39.

[24] Mojon, B. and M. Ciccarelli (2005), "Global Inflation", ECB Working Paper No. 537.

[25] Mönch, E. (2005), "Forecasting the Yield Curve in a Data-Rich Environment: A No-Arbitrage Factor-Augmented VAR Approach", ECB Working Paper series No. 544.

[26] Mönch, E. (2006), "Term Structure Surprises: The Predictive Content of Curvature, Level, and Slope", Working Paper.

[27] Perignon, C., D.R. Smith and C. Villa (2007), "Why common factors in international bond returns are not so common," Journal of International Money and Finance, 26(2), pp. 284-304.

[28] Sargent, T.J. and C. Sims (1977), "Business Cycle Modelling Without Pretending to Have Too Much a Priori Economic Theory," in New Methods in Business Cycle Research, Procedures from a conference (Minneapolis: Federal Reserve Bank of Minneapolis, 1977, pp. 45-110).

[29] Stock, J.H. and M.W. Watson (2002*a*), "Macroeconomic forecasting using diffusion indexes," Journal of Business and Economic Statistics, 20, pp. 147-162.

[30] Stock, J.H. and M.W. Watson (2002*b*), "Forecasting using principal components from a large number of predictors," Journal of the American Statistical Association, 97, pp. 1167-79.

[31] Wang, Z., J. Yang, and Q. Li (2007), "Interest Rate Linkages in the Eurocurrency Market: Contemporaneous and Out-of-Sample Granger Causality Tests" . Journal of International Money and Finance, 26, pp.86-103.

Table 1. Out of sample forecasts: Germany

$MSFE_Y/MSFE_{RW}$						
Iterative	1-steps		6-steps		12-steps	
m	GE	All	GE	All	GE	All
1	7.813	4.234	1.877	0.752	1.0092	0.671
2	3.096	1.778	1.774	0.764	1.0193	0.544
3	2.170	1.456	1.693	0.772	1.1507	0.517
4	1.713	1.257	1.577	0.738	1.3388	0.510
5	1.486	1.168	1.507	0.710	1.6026	0.521
6	1.355	1.134	1.491	0.704	1.9307	0.555
7	1.255	1.110	1.524	0.720	2.3072	0.614
8	1.163	1.068	1.604	0.751	2.7291	0.697
9	1.089	1.011	1.736	0.798	3.2053	0.808
10	1.072	0.972	1.929	0.865	3.7464	0.949

Notes: The table presents the results from the out of sample forecasts of the domestic (GE) and international (All) yields-only (Y) models compared to the RW forecast. The results displayed in the columns represent the MSFE of the yields-only model ($MSFE_Y$) divided by the MSFE of a RW ($RMSE_{RW}$) for $h = 1, 6$ and 12 steps ahead and for maturities $m = 1$ to 10.

Table 2. Out of sample forecasts: US

$MSFE_Y/MSFE_{RW}$						
Iterative	1-steps		6-steps		12-steps	
m	US	All	US	All	US	All
1	1.076	1.493	1.091	1.662	0.981	1.247
2	1.140	1.489	1.071	1.7222	0.994	1.350
3	1.046	1.404	1.045	1.885	1.069	1.558
4	0.994	1.339	1.071	2.127	1.213	1.875
5	0.983	1.325	1.136	2.242	1.405	2.260
6	0.982	1.361	1.243	2.838	1.666	2.755
7	1.001	1.428	1.401	3.420	2.041	3.450
8	1.014	1.527	1.529	3.859	2.392	4.092
9	1.065	1.670	1.757	4.503	2.788	4.776
10	1.268	2.142	2.217	5.617	3.406	5.782

Notes: The table presents the results from the out of sample forecasts of the domestic (US) and international (All) yields-only (Y) models compared to the RW forecast. The results displayed in the columns represent the MSFE of the yields-only model ($MSFE_Y$) divided by the MSFE of a RW ($RMSE_{RW}$) for $h = 1, 6$ and 12 steps ahead and for maturities $m = 1$ to 10.

Table 3. Out of sample forecasts: UK

			$MSFE_Y / MSFE_{RW}$			
Iterative	1-steps		6-steps		12-steps	
m	UK	All	UK	All	UK	All
1	0.968	1.419	0.865	1.875	0.688	1.650
2	1.012	1.193	1.082	1.382	0.894	1.076
3	1.076	1.116	1.263	1.196	1.089	0.854
4	1.135	1.065	1.352	1.110	1.209	0.749
5	1.163	1.039	1.372	1.082	1.278	0.704
6	1.152	1.037	1.349	1.099	1.321	0.697
7	1.115	1.062	1.306	1.155	1.354	0.721
8	1.076	1.125	1.259	1.250	1.388	0.772
9	1.063	1.236	1.221	1.386	1.427	0.851
10	1.094	1.407	1.119	1.562	1.475	0.962

Notes: The table presents the results from the out of sample forecasts of the domestic (UK) and international (All) yields-only (Y) models compared to the RW forecast. The results displayed in the columns represent the MSFE of the yields-only model ($MSFE_Y$) divided by the MSFE of a RW ($RMSE_{RW}$) for $h = 1, 6$ and 12 steps ahead and for maturities $m = 1$ to 10.

Table 4. Forecast performance: Germany

m	Benchmark: All vs: RW&GE			Benchmark:RW vs: All			Benchmark:GE vs:All		
	1 steps	6 steps	12 steps	1 steps	6 steps	12 steps	1 steps	6 steps	12 steps
1	1.000	0.109	0.090	1.000	0.000	0.001	0.000	0.000	0.014
2	1.000	0.092	0.037	0.995	0.002	0.000	0.000	0.000	0.002
3	1.000	0.134	0.050	0.987	0.007	0.000	0.000	0.000	0.000
4	0.993	0.142	0.074	0.943	0.004	0.000	0.000	0.000	0.000
5	0.980	0.148	0.123	0.888	0.006	0.000	0.004	0.000	0.000
6	0.972	0.182	0.188	0.871	0.014	0.003	0.017	0.000	0.000
7	0.980	0.245	0.264	0.842	0.027	0.012	0.056	0.000	0.000
8	0.945	0.348	0.377	0.767	0.058	0.044	0.115	0.000	0.000
9	0.868	0.459	0.539	0.603	0.124	0.161	0.143	0.000	0.000
10	0.722	0.608	0.739	0.422	0.255	0.426	0.090	0.000	0.000

Table 5. Forecast performance: US

m	Benchmark: All vs: RW&US			Benchmark:RW vs: All			Benchmark:US vs:All		
	1 step	6 steps	12 steps	1 step	6 steps	12 steps	1 step	6 steps	12 steps
1	0.968	0.935	0.754	0.995	0.997	0.950	0.999	1.000	1.000
2	0.999	0.916	0.797	0.999	0.999	0.964	0.998	1.000	1.000
3	0.948	0.884	0.9005	0.996	0.999	0.994	0.999	1.000	1.000
4	0.805	0.904	0.977	0.990	1.000	0.999	0.999	1.000	1.000
5	0.762	0.952	0.998	0.989	1.000	1.000	0.998	1.000	1.000
6	0.764	0.982	1.000	0.994	1.000	1.000	0.999	1.000	1.000
7	0.825	0.996	1.000	0.997	1.000	1.000	1.000	1.000	1.000
8	0.857	0.999	1.000	0998	1.000	1.000	0.999	1.000	1.000
9	0.946	1.000	1.000	0.999	1.000	1.000	1.000	1.000	1.000
10	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Notes: The tables present bootstrapped p-values derived for $h = 1, 6$ and 12 steps ahead and maturities $m = 1$ to 10 from three different tests: The White's "reality check", where the international model ("All") is tested against the domestic and the random walk ("RW") and two pairwise bootstrap excercises where the RW and the domestic model are tested versus the international model. In Table 4 the domestic country is considered to be Germany ("GE") and in Table 5 the US ("US").The null hypothesis states that none of the alternative specifications has superior forecast accuracy than the benchmark.

Table 6. Forecast performance: UK

	Benchmark: All			Benchmark:RW			Benchmark:UK		
m	vs: RW&UK			vs: All			vs:All		
	1 step	6 steps	12 steps	1 step	6 steps	12 steps	1 step	6 steps	12 steps
1	0.906	0.965	0.613	0.991	1.000	0.999	0.982	0.995	0.994
2	0.717	0.961	0.637	0.961	0.992	0.697	0.924	0.886	0.761
3	0.764	0.987	0.265	0.910	0.951	0.079	0.783	0.506	0.051
4	0.956	0.981	0.080	0.835	0.901	0.003	0.435	0.204	0.002
5	0.952	0.976	0.046	0.777	0.897	0.000	0.205	0.106	0.000
6	0.949	0.989	0.049	0.777	0.946	0.000	0.166	0.099	0.000
7	0.980	0.997	0.072	0.872	0.991	0.000	0.264	0.151	0.000
8	0.973	0.999	0.134	0.953	0.998	0.001	0.542	0.293	0.000
9	0.926	1.000	0.268	0.984	0.999	0.014	0.840	0.536	0.000
10	0.909	1.000	0.568	0.992	0.999	0.150	0.964	0.777	0.000

Notes: The tables present bootstrapped p-values derived for $h = 1, 6$ and 12 steps ahead and maturities $m = 1$ to 10 from three different tests: The White's "reality check", where the international model ("All") is tested against the domestic ("UK") and the random walk ("RW") and two pairwise bootstrap excercises where the RW and the domestic model are tested versus the international model. The null hypothesis states that none of the alternative specifications has superior forecast accuracy than the benchmark.