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# BENCHMARK BONDS INTERACTIONS UNDER REGIME SHIFTS

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**Abstract**

In the present paper we examine interactions among five benchmark ten year government bonds, namely those of the US, Germany, France, Italy and the Netherlands. Our aim is to illustrate empirically a network of interactions existing among the major bond markets of Europe and the US market taking into account shifts in the underlying stochastic processes. For this purpose, and in contrast to the rest of the relevant empirical literature, after specifying the long-run equilibrium relations we estimate the linkages between the bond markets as subject to hidden Markov chains, by applying the Markov Switching Vector Error Correction framework (MS-VECM). This formulation is found to efficiently reflect the shifts brought about by significant economic events, such as the European monetary unification. As a result we illustrate different short-run relations referring to the periods before and after monetary union. Overall, our empirical results indicate that stronger interactions between the markets of the system exist in the period after the EMU. Also, by means of a variance decomposition analysis we assess leader-follower relations which indicate that the benchmark status of bonds has changed since the introduction of the common monetary policy framework in Europe.

*Keywords:* Financial integration; bond markets; benchmarks; Markov Switching
*JEL Classification:* F21, F37, G12, G15

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# 1. Introduction

In this paper we aim at illustrating empirically the causal links between several European long-term government bonds and the US Treasury bond. In order to place our work in the empirical literature concerning bond pricing, we can note that our empirical framework relates to that of Clarida *et al.* (2006) as in both papers emphasis is given to bond pricing issues, while several other works have dealt with European bond markets in the past[1]. However, there exist some important differences as these authors take into account unobserved regime shifts occurring between yields of the same sovereign issuer, differing in their term to maturity, whereas we investigate the interactions among bonds of the same term to maturity, issued by different (sovereign) entities.

The main concern of this paper is to illustrate the interactions among the benchmark bonds examined. In this context, although financial integration is an issue attracting an increased volume of empirical research, to the best of our knowledge the paper at hand consists the first empirical examination in which a regime switching framework is used to explore causal relations among major international bond markets. As a result, our contribution to the empirical literature on financial integration is that we illustrate the significance of taking into account shifts when estimating the degree to which bond markets interact with each other. In our poinion, the most prominent candidates for this empirical exercise are the European government bond markets, as the intra-European exchange rate risk has been eliminated between them, which in turn provides a potential source of a significant regime shift.

Until recently, empirical research on European bond markets has concentrated on issues of common pricing processes being subject to the structure of the markets and the process of convergence of the institutional framework. Additionally, economic integration and increased international capital mobility are among the factors with potentially strong effects on the degree of financial integration. To begin with the structure and institutions of markets, Pagano and von Thadden (2004) argue that infrastructural and institutional convergence under EMU have contributed to the

[1] See, for example, Pagano and von Thadden (2004), Codogno *et al.* (2003) and Haug *et al.* (2000).

convergence of the pricing processes in European bond markets. Aizenman and Glick (2008) attribute the increased synchronization of financial market movements in the UK with those of Europe and the US to the coordination of monetary policies. Additionally de Goeij and Marquering (2006), among others, report results indicating that macroeconomic announcements have a strong effect on bond markets movements. These results, combined with the findings of Artis *et al.* (2004), reporting increased, although not complete, European business cycle convergence, point to a potential explanation for increased European bond markets integration. We deem that a natural follow-up to this investigation is to show that interactions between financial markets are subject to regime switching effects due to changes in the economic activity and the structure of the economy.

The breadth of the literature dealing with financial integration is large while the empirical investigations can broadly be categorized into two strands, according to the objectives of the investigation and the methodology used. The first category aims at identifying common patterns and causality relations in markets' movements, stemming from common components of the underlying pricing processes. Specifically, several papers, such as Baele *et al.* (2004), Codogno *et al.* (2003) and Haug *et al.* (2000) for European markets and Fidora *et al.* (2007) and Yang *et al.* (2004) for international markets, examine the co-movements of various financial markets segments, mainly by using VARs and cointegration techniques. These authors agree that international financial markets are subject to common factors influencing their pricing processes, while several of these papers justify their results by an appeal to increasing financial integration during the nineties. The second strand of the literature investigates interactions under the prism of contagion. Methodologically, volatility spillover effects among markets are examined mainly by applying various GARCH methodologies (see Hunter and Simon, 2005, Kim *et al*., 2006, Skintzi and Refenes, 2006 and Christiansen, 2007, on bond markets).

However, as argued by Neal (1985), the effects of financial integration are not permanent, while our perspective implies that the question of the existence of financial integration cannot be answered binomially, but is rather more complex. The underlying thesis of a changing degree of financial integration due mainly to developments in the economy is the epicentre of the present paper. Government bond markets were chosen for two reasons. The first is their fundamental importance for the entire financial sector. The second is that they have not attracted such a large volume of research on the issue of financial integration compared to other financial markets such as equities markets (Kim *et al.*, 2006).

In this paper, we argue that financial markets interactions are subject to shifts because of changes in the underlying economic conditions. Thus, we employ an empirical investigation framework, which enables us to take into account both the stochastic properties of the underlying variables and the changing nature of economic conditions, in order to achieve the final aim of the paper. Specifically, we focus on finding common causal patterns among various government bond markets, after having allowed for unobserved Markov switching effects to be reflected in the interactions.

In light of recent methodological advances concerning the illustration of endogenous shifts in time series, the empirical assessment of regime switching effects in the underlying interactions among financial markets is a natural follow-up to previous works on the broader issue of financial integration. To the best of our knowledge this is the first paper formulating a non-linear framework for the investigation of issues relating first to the causal relations among bond markets and second to the benchmark status in the bond markets' sector. Our empirical investigation focuses on major European government bond markets and the US Treasury market.[2] Within this framework we examine the existence of common trends in the system and attempt to detect shifts that follow unobserved Markov chain probabilistic functions, in the underlying VECM. Similar investigations can be found in Bredin and Hyde (2008), who study interactions between international and small stock markets as subject to regime switches by using the smooth transition regression model, Davies (2006), focusing on regime switches in long-run equilibrium relations among equity markets, and Yang *et al.* (2004) who apply a Threshold VAR methodology. Finally, a similar, non-linear, examination is provided by Sarno and Valente (2005), who formulate a Markov switching framework for the

[2] The EMU markets of the set (namely Germany, France, Italy and the Netherlands) were chosen under the criterion of significance, as they either reflect benchmark characteristics (Germany and France for the whole system of EMU bond markets and Italy for the high-yielders' sector according to Lane, 2006) or concentrate increased liquidity and foreign portfolio participation (such as the Netherlands, according to Lane, 2006, and Favero *et al.*, 2006).

examination of spillover effects among three major equity market indices and the corresponding futures contracts written on them.

Empirically, the present paper has various implications, providing answers to questions concerning international bond markets interactions. We show that the markets under investigation show an increased degree of integration, in line with findings of Holmes and Maghrebi (2006) for a very similar group of money markets. Having argued that the empirical framework should take into account changes in the economic environment, we employ the MS-VECM methodological framework, established by Krolzig (1997). Our empirical results reflect the effects of the common euro area monetary policy framework, as the regime shift occurs in the period during which the exchange rates at which countries would join the union were being finalised. As a result, by revealing the impact of European monetary unification on the interactions among government bond markets, we argue that the launch of EMU constitutes a point in time associated with a significant regime shift in the interactions among the markets examined. To the best of our knowledge this is the first paper to illustrate, endogenously[3], this effect. Finally, we provide an explicit answer to the question of benchmark status in European bond markets. Our results indicate that, in line with recent literature, the Bund has experienced a weakening of its benchmark status in the post-EMU era. In addition, our results provide a more complex picture with respect to the benchmark characteristics, suggesting that they vary with the duration of the causal effects.

In section 2 the theoretical background is summarized in a brief literature review, in order to provide an overview of the technical, theoretical and empirical considerations associated with the issue of financial market linkages. Section 3 describes the empirical framework, by analyzing the data and discussing the econometric methodologies applied. Section 4 reports the results of the empirical investigation, while section 5 provides some brief concluding remarks.

[3] Abad *et al.* (2009) also report strengthening of interactions among EMU government bond markets. However, in their analysis results are drawn from a comparison between EMU and non-EMU bond markets and as results they do not allow for a differentiation of regimes prior and after monetary unification.

## 2. Literature review

Financial market interactions constitute an intertemporal topic for economic research while during the last two decades it has attracted increasing attention in the empirical finance research literature. Campbell and Ammer (1993) examine the linkages between international bond and equity markets in order to trace common pricing patterns. Departing from pricing theories such as the CAPM, Bekaert and Harvey (1995) examine the common movements in international stock markets and assess the dominant characteristics of the US market, thus formulating a system where lead-lag characteristics exist. Chen and Knez (1995) touch upon theoretical and technical sides of the subject and underline the need for incorporating the stochastic characteristics of financial time series when examining financial integration and propose a discount factor methodology in order to assess the interactions between financial markets.

The issue of the data generation process for interest rates has attracted various empirical treatments and even conflicting views in the empirical literature. Specifically, there exists a vast volume of empirical literature treating interest rates as subject to $I(1)$ processes, mostly on the basis of the results produced by conventional unit root tests. On the other hand, finance theory is based on the assumption of stationary interest rates which is justified on the bounded variance of interest rates.[4] The conflicting empirical results on the stochastic properties of interest rates are usually due to the low power of most conventional unit root tests in the presence of stationary – albeit persistent – stochastic processes with a root below but very close to unity.

On the stochastic properties of the data under examination we make reference to just few empirical works which argue in favour or against the non-stationarity of interest rates. Katsimbris and Miller (1993) study interest rate linkages in the European Monetary System and fails to reject the assumption of non-stationary European interest rates. More recently, Clarida *et al.* (2006), investigating issues of the term structure of interest rates dynamics, incorporate Markov Switching effects after having tested the interest rate data

[4] However it is interesting to remark that in the recent crisis we observed several negative quotations on Treasury bill yields in the period November and December 2008 (e.g. on the 11th and the 19th of December 2008). Interested researchers should refer to data of the secondary market yields of the T-bill with a term to maturity of 4 weeks reported by the Federal Reserve Board (H.15 selected interest rates).

set for unit roots. Their tests indicate $I(1)$ characteristics across the whole of the yield curve. On the same topic, Tillmann (2007) formulates a regime switching cointegration framework for the examination of the term structure of interest rates for the US. By contrast, Sarno *et al.* (2007) make use of more powerful unit root tests and report findings of stationarity of bond yields. Finally, Lanne (2000, 2001) has argued that interest rates are governed by near unit roots in which case standard cointegration tests could falsely identify non-stationarity in some long-run relations, thus underestimating the number of cointegrating vectors in the system. Hjälmarsson and Österholm (2009) propose the preliminary examination of the decomposition of the cointegration space with long-run exclusion tests, in order for the structure of the cointegrating vectors to be accurately estimated in the presence of near-integrated series. They argue that in case a variable is not contained in the cointegration space, then the specific LR tests will confirm its exclusion.

Although there is strong economic reasoning for the stationarity of bond yields the vast majority of the relevant literature relies on the outcome of standard unit root tests and, as a matter of empirical convenience, moves on to apply cointegration analysis which can be further used to reach conclusions about financial integration. For example, Haug *et al.* (2000) test for the existence of a single common stochastic trend among the returns of several European financial markets as a precondition for full financial integration. They state that although convergence has advanced, the hypothesis of full integration cannot be supported based on the finding of more than a single stochastic trend in the system. Adopting this approach, we pose the first precondition for estimating the degree of financial integration to be the finding of a single common stochastic trend driving the system. Subsequently, the imposition of restrictions on the coefficients of the long-run equilibrium relations permits an assessment of the nature of the financial integration. The theoretical approach of parity relations, formulated by Mishkin (1984), is then used to specify the theoretically imposed restrictions in order to answer the central question of the present paper. However, a more restricted perception is employed here as we do not focus on the decomposition of the premia in the parity relations.

Previous work making use of cointegration analysis of relations between long or short-term rates include, but are not restricted to, Baum and Barkoulas (2006) and

Holmes and Maghrebi (2006). The latter, in order to accept financial integration, test for parity in the underlying long-run equilibria among European money markets by restricting the cointegration vectors to (1 -1)′,. Centeno and Mello (1999) assess the degree of financial integration in European money and loan markets by using cointegration techniques and find that, although money markets are found to be fully integrated, the same could not be said for the market for loans.

The results of our analysis are in line with those for money market reported by Holmes and Maghrebi (2006), who investigate parity relations in regimes of high and low volatility. Additionally, our findings on the parity relations among the markets examined are relevant to research on sovereign bond spreads, either for EMU or international bond markets; Manganelli and Wolswijk (2007) relate fiscal discipline to government bond spreads in EMU countries and Lane (2006) argues that liquidity features and different sectoral characteristics are responsible for the remaining spreads between European government bonds. Codogno *et al.* (2003) provide evidence of higher integration between European bond markets after the introduction of the common monetary policy framework. Our results extend these findings by specifying the patterns of interactions among the bond markets both before and after monetary unification.

Additionally, we follow von Hagen and Fratianni (1990) on the characteristics a market should have to be dominant, that is to cause the rest of the markets but to be least caused by them. Of course the causal relations are reflected in the regime switching framework by incorporating Markov switching effects into the short-run dynamics. More specifically, by allowing the interactions of the system to be governed by a non-linear process, we identify changes in markets interactions following the implementation of the common monetary policy framework in the euro area while at the same time these changes result in changing the benchmark characteristics in the system. This is shown through a variance decomposition analysis which measures the contribution of individual shocks to the variance of the rest of the system (see Engsted and Tangaard, 2004).

# 3. Empirical investigation framework

## 3.1 Description of the data

As already mentioned, the present analysis focuses on the major European bond markets, i.e. those of Germany, France, Italy and the Netherlands together with the US Treasury bond market. The data set contains on-the-run government bonds (benchmark bonds) with a term to maturity of ten years, from which we draw results from secondary market yields for the time period 1992:1-2007:1. The source of the data set is Thomson Financial Datastream, which compiles data for benchmark bonds issues reported from each country's central bank according to the IMF's statistical reporting standards.

Using data on benchmark ten-year bonds eliminates any potential liquidity constraints that could blur the results, as one of the determinants of benchmark status is their high trading volume in the respective secondary markets. Specifically, the liquidity premium of the time series we use varies only according to systemic factors, as the benchmark status is relative to increased trading volumes (on-the-run ten-year government bonds with the highest trading volume). However, this liquidity premium is small when compared to the rest of the issues of the same sovereign, with a similar term to maturity.

Finally, the period we examine is characterized by several of the major financial and economic developments that took place during the nineties. In particular, the lower boundary of our data period is set to capture the period immediately after the Maastricht Treaty, which triggered the convergence procedure to be followed towards monetary unification. Until 1999, financial markets were occasionally hit by turbulence arising from the Mexican peso crisis, the Asian crisis and the LTCM failure. On the 1st of January 1999 the common European monetary policy framework was launched, rendering this point in time a reference date, set to reflect an increased degree of economic and financial integration among the EMU countries. From 1999 onwards, several developments have had significant effects on financial markets, such as the Argentinian sovereign debt crisis, the bursting of the 'dot.com' bubble, the 2001 US recession and the oil price increase combined with the gradual increase in US deficits.

All these effects have had a significant impact on financial markets and, consequently, bond markets. As a result, there exists a case for examining the specific period with the aim of detecting regime shifts in the underlying government bond markets interactions. However, we expect that in case markets interact closely, i.e. financial integration is evident, potential regime shifts should stem from events with increased importance for the financial sector.

### 3.2 Methodological framework

The most natural methodology to be applied in order to estimate the causal linkages between government bond yields is the Vector Autoregression (VAR) formulation. Let (1) represent the general VAR process.

$$X_t = c + \sum_{i=1}^{l} A_i X_{t-i} + u_t \qquad (1)$$

In (1), the vector $A$ contains coefficients on the lagged variables, while $X$ represents a ($nx1$) vector containing the yields of the government bonds and $u$ is a ($nx1$) multivariate normal random error with mean zero and a variance-covariance matrix that is independent across time periods. In order to specify the appropriate econometric methodology for our question, we examine whether the data we use contains unit roots. Specifically, we employ the standard tests of Dickey and Fuller (1981) and the more efficient alternatives proposed by Elliott *et al.* (1996) and Ng and Perron (2001), as well as the stationarity tests of Kwiatkowski *et al.* (1992). All tests indicate that our series are characterized by non-stationarity (see Table 1). The Elliot *et al.* (1996) test addresses the problem of the low power of the ADF test relative to local alternatives by using a GLS detrending procedure. Similarly, the Ng and Perron (2001) GLS version of the Phillips-Perron tests addresses the size distortion and the low power of the ADF test induced by the presence of a large negative moving average root and / or a large autoregressive root. In light of potential near unit root problems, we also test for long-run exclusion. According to Hjälmarsson and Österholm (2009), in case no time series are found to be excluded from the cointegration space, the specification of the system is correct, both in the case of unit roots and near unit roots.

Consequently, letting the bond yields of vector $X$ be governed by unit or near-unit root processes we rely on cointegration analysis techniques in order to specify the long-run equilibrium relations in the system. Therefore, we formulate, equivalently, the system's relations as indicated by equation (2),

$$\Delta X_t = \mu + \Pi X_{t-1} + \sum_{i=1}^{l-1} \Gamma_i \Delta X_{t-i} + u_t \ . \qquad (2)$$

The system of interactions among the markets is formulated in an error correction form represented by equation (2) in which $\mu$ stands for the restricted constant, $\Pi = \alpha\beta'$ stands for the matrix of cointegration vectors of the system, in which $\beta$'s stand for the cointegration relations, $\alpha$'s for the adjustment coefficients, while $\Gamma$ is the matrix containing the lagged variables' coefficients.

Applying the $\lambda_{Trace}$ tests, we estimate the number of cointegration vectors and consequently the number of trends that govern the cointegrated system's stochastic process while we examine recursively the rank of the cointegration space by applying the tests of Hansen and Johansen (1999). In the presence of a convergence process, a positive trend of the value of the trace test will be found. Furthermore, in case a single common stochastic trend is found to exist this would indicate that the specification of the system under cointegration analysis is robust, even if the data are characterized by near unit root properties as well[5].

The cointegration relations are then decomposed into their constituents, namely the variables' weights of the long-run equilibrium relations, $\beta$. At this stage we apply the likelihood ratio tests to examine the restrictions imposed theoretically, namely the parity

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[5] Let $n$ stand for the number of (non-stationary) variables in the system, while $p$ denotes the true number of stationary long run equilibrium relations of the data and $r$ ($r=n-p$) indicates the number of stochastic trends existing in the system after cointegration effects are taken into account. According to Elliott (1998) and Lanne (2000 and 2001), there is the potentiality that the standard cointegration tests would falsely reject stationarity of a linear combination of the variables in case the system contains data with near unit root properties (that is $p \geq p_{std}$, where $p_{std}$ stands for the cointegration rank under standard inference). Now let $p_{nur}$ denote the cointegration rank in case near unit root properties were taken into account (by definition $p_{nur}=p$, $p_{nur} \geq p_{std}$). However as indicated by the unit root test results reported in Table 1, the data set is non-stationary, which implies that $r \geq 1$ and $p<n$. Then in case standard cointegration rank tests result to $p_{std}=n-1$, that is a single common stochastic trend is found to exist in the system, then $p_{nur} \equiv p_{std}=n-1$.

relations. For this purpose we test whether the hypothesis that the long-run structure is restricted to a (1 -1)` formulation is confirmed. This hypothesis is illustrated, in a multivariate setting, by a 5x5 matrix of the following composition:

$$H \quad : R \cdot \beta = \begin{bmatrix} -1 & 1 & \ldots & 0 \\ -1 & 0 & \ldots & 0 \\ \ldots & \ldots & \ldots & 0 \\ -1 & 0 & \ldots & 1 \end{bmatrix} \tag{3}$$

Specifically, we argue that should the government bond markets under examination be strongly interacting with each other in the long run, the underlying equilibrium relations will reflect close co-movements thus confirming the parity hypothesis. We introduce parity restrictions in the system simultaneously, as our purpose is to examine the degree of financial integration of the system as a whole. However, in the case that the parity test confirms stationarity of the underlying spreads, the findings should not be interpreted as reflecting only different risk premia. Specifically, different coupon yields of the benchmark bonds at the time of issuance could reflect other factors as well. Thus, even though the risk premia could stand as significant components of the underlying spreads, their decomposition into risk and other factors would necessitate a separate analysis, a task that is beyond the scope of the present paper.

Thus, in case the restrictions in (3) are not rejected, our model implies that yield changes respond not only to disequilibrium in the relevant bond market, in relation to the benchmark bond market, but also to the respective disequilibrium of the other bond markets, exhibiting therefore no *separation in the equilibrium correction*. However, still our model will imply that there are no spillover effects, among the markets and, thus, in the long run will exhibit *separate cointegration* (see Sarno and Valente, 2005). Also, we impose no exclusion restrictions on matrix $\Gamma$, i.e. on the dynamic adjustment towards the long-run equilibrium. Overall therefore our model is characterized by *partial separation* since these spillover effects, from other markets, in the dynamic process of bond yields are well documented in the relevant literature (Ang and Bekaert, 2002).

We then proceed with the application of a Markov Switching framework on the short-run structure of the system. Eq. (4), below, illustrates the methodological framework applied in order to capture Markov Switching effects in the underlying short-run decomposition of the VECM,

$$\begin{aligned}&\Delta X_t = \mu(s_t) + \alpha(s_t)\beta X_{t-1} + \sum_{i=1}^{l-1} \alpha_i(s_t)\Delta X_{t-i} + u_t \\ &u_t \sim (0, \Sigma(s_t))\end{aligned}. \tag{4}$$

We impose an unobserved state dependent variable, *s,* that is governed by a Markov Switching ergodic chain stochastic process in the short-run decomposition of the cointegrated system of eq. (2). Furthermore, the variable $s_t$ is restricted to capture two different states, that is $s_t \in \{0,1\}$ with probabilities distributed as

$$p_{ij} = \Pr ob[s_{t+1} = j \mid s_t = i], \qquad \sum_{j=1}^{M} p_{ij} = 1 \qquad \forall i, j\ . \tag{5}$$

As shown in eq. (4) we expect that both the constant and the volatility of the system will be subject to different regime categorization, thus counting for mean reversions and high/low volatility states respectively. As far as the coefficients are concerned, both coefficients on the lagged variables and the adjustment coefficients of the error correction terms are allowed to exhibit regime switching behaviour.

According to the methodological framework formulated by Krolzig (1997) the MS-VECM is estimated by applying the Expectations Maximization (EM) algorithm. Specifically, assuming that $s_t \in \{0,1\}$ and defining the probabilities $\Pr ob[s_t = 0 | s_{t-1} = 0] = p$ and $\Pr ob[s_t = 1 | s_{t-1} = 1] = q$, then the system's Markov switching effects can be estimated under the following specification of the transition matrix:

$$P = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} \tag{6}$$

where,

$$\begin{aligned}&p_{11} = \Pr ob[s_t = 0 | s_{t-1} = 0] = p && p_{12} = \Pr ob[s_t = 1 | s_{t-1} = 0] = 1 - p \\ &p_{21} = \Pr ob[s_t = 0 | s_{t-1} = 1] = 1 - q && p_{22} = \Pr ob[s_t = 1 | s_{t-1} = 1] = q\end{aligned}. \tag{7}$$

In order to examine the benchmark status characteristics of each of the sovereign bonds used in our model we apply a variance decomposition analysis on the estimated MS-VECM for each one of the two regimes. First, for each of the estimated models in (4), corresponding to each of the two regimes, we derive its corresponding AR representation in levels by exploiting the link between the AR and the VECM representations shown, among others, in Mills (1999):

$$\begin{aligned} \hat{A}_1 &= \hat{\Pi} + \hat{\Gamma}_1 \\ \hat{A}_i &= \hat{\Gamma}_i - \hat{\Gamma}_{i-1}, \quad i = 2,3,...l-1. \\ \hat{A}_l &= -\hat{\Gamma}_{l-1} \end{aligned} \tag{8}$$

Then we follow the methodology of Ehrmann *et al.* (2003) for the production of regime dependent impulse responses and therefore of the variance decomposition analysis where a Choleski decomposition of the variance – covariance matrix ensures its exact identification.

## 4. Empirical results

Table 2 contains the results of the cointegration rank tests and the various hypotheses tested according to the theoretical considerations of financial integration. According to the cointegration rank tests there exist four cointegration vectors[6]. This initial result has various implications for the continuation of our investigation and for the interpretation of the subsequent findings. First, as mentioned above, the finding of four cointegrating vectors leaves room for just one common stochastic trend in the data set. This finding passes the threshold set by Haug *et al.* (2000), who presuppose the existence of one common trend in order for financial integration not to be rejected. Of course this result is a necessary but not sufficient condition for a robust answer to the central question of the degree of integration. Next, Figure 1 illustrates the results of various tests with implications for the cointegration space, run recursively for the whole sample period. As expected the positive slope of the rank tests after 1997, a date that coincides

[6] According to critical values provided both by MacKinnon *et al.* (1999) and Osterwald-Lennum (1992) for the case of a restricted constant in the cointegration vectors.

with the adoption of the Stability and Growth Pact, indicates increased convergence characteristics in the system. However, the presence of four cointegrating vectors is established only towards the end of our sample. The constancy test of the eigenvalues of the system are also illustrated in Figure 1. This test exploits the fact that there is a unique relationship between the eigenvalues and the cointegrating vectors. The results indicate that there exists a shift in the system related to the adoption of the common European monetary framework in the sense that the values of the four eigenvalues remain almost unchanged after 1999.

In order to investigate whether the system's variables consist of an integrated total of financial markets, we test several hypotheses concerning questions first about whether all markets participate in the formulation of the equilibrium relations and then on the parity characteristics inherent in the underlying relations. Testing for the participation of all the variables in the long-run equilibrium relations allows us to draw results on the composition of the cointegration space. In order to have an integrated system, we need the system to be *irreducibly cointegrated* (see Davidson, 1998) and the long-run equilibria to take the form of parity relations, as well. The exclusion tests indicate that the hypothesis of excluding a series from the cointegration space is rejected for every variable of the system, thus indicating that the system is *irreducibly cointegrated*.

Next, we specify the decomposition of the cointegration space. Normalising the cointegration vectors against the Bund's yields we obtain the unrestricted formulation of the long-run relations. The estimated parameters of the cointegration space are difficult to interpret since there is a strong co-linearity in the long-run among the bond yields which blurs the contribution of each one of them in the cointegrating relations. However, it is worth noting that the estimated parameters of the Italian bond and the US Treasury, which are less co-linear with the other three, are substantially smaller in absolute terms than the rest. In order to get a clearer interpretation of our results we introduce restrictions in each cointegration relation, examining the hypothesis that the system's bond yields are cointegrated with the Bund yields in a bilateral way. This step is necessary before examining for the existence of parity in the underlying relations. The results confirm the stationarity of each long-run relation under a bilateral cointegration specification with the Bund.

As a result, we next test for parity in the long-run equilibrium relations of the system. As mentioned in the methodological section, we lift the strict interpretation of the parity relations, allowing for risk premia and other factors to be captured by the constant terms in the cointegration vectors. The results indicate that the system's long-run relations are well-represented by the parity relations. Overall these findings are in line with those reported by Holmes and Maghrebi (2006) on money markets. The evidence supporting financial integration is provided by the cointegration space decomposition, both in terms of the elimination of the idiosyncratic properties of the stochastic trends of the system and in terms of the parity encompassed in the underlying long-run equilibria. The close long-run co-movements between the Bund and the Treasury bond, reflect the significant linkages that have been established between the underlying financial markets. Additionally, the German bond evidently closely interacts in the long run with the French and the Dutch bonds. Again, the long-run structure of the underlying relations is significantly explained by parity relations with the addition of a constant capturing, possibly, liquidity premia reported in the previous literature. (see, Codogno *et al,* 2003, Lane, 2006 and Pagano and Favero, 2002). Finally, the Italian bond closely interacts with the German Bund although a strict interpretation of the parity hypothesis has to be rejected. The relationship between the Italian and German bonds could well be stated to reflect the least close long-run interactions in the system. However, one should bear in mind that the Italian bond belongs to a different investment sector being the benchmark for high-yielders in the euro area, according to Lane (2006). Still, the establishment of a significant long-run relation that is capable of lifting a stochastic trend of the system is a finding worth highlighting, indicating significant co-movements in the long run.

Next we turn to the investigation of the short-run dynamics of the system both in relation to the adjustment towards the long-run equilibria and the direct linkages among the underlying markets, as described by the interactions between the lagged variables in the underlying VECM. In order to argue for the introduction of Markov switching characteristics in the system's VECM, we examine comparatively the properties of the MS-VECM against the alternative standard linear representation. The respective results are reported in Table 3.

The regime switching formulation clearly provides enhanced information as compared to the linear VECM. Specifically, the Akaike Information Criterion indicates that the Markov switching formulation contains higher informational value for the system's short-run relations, compared to the linear one. Additionally, using the Regime Classification Measure, *RCM*, as reported in Ang and Bekaert (2002), the adopted Markov Switching model (quoted MSIAH according to Krolzig, 1997) provides an optimal separation of the two different states of the system. Observing the probabilistic classification of the period under examination according to the dominant regime in Figure 2, suggests that the MS-VECM formulation captures a regime shift related to European monetary unification in 1999.

Table 4, reports the short-run dynamics, as captured by the MS-VECM formulation, for each of the two different regimes of the system. It is notable that the cointegration space, consistent with the parity relations among the bonds under investigation, exercise only limited adjustment power to the system's variables in the first regime. Specifically, only the Treasury and the Italian benchmark ten-year bond are found to have been affected significantly by the spreads underlying the long-run relations.

In the first case the spreads between the Bund and the Treasury and between the German and French benchmarks are indicated to be affecting the Treasury yields, before the launch of the common monetary policy. This effect clearly reflects the sharing of information among financial markets across the US and the Europe, probably due to capital mobility and common pricing factors. However, the positive sign of the coefficients is not indicative of an adjustment process. Rather it is indicative of the potential exogeneity of the Treasury yields. More specifically, given that in 62% of the observations captured by the first regime, the spread between the Treasury and the Bund was negative, this finding is indicative of a tendency towards lower Treasury yields. This is in line with the common perception about the benchmark characteristics of the Treasury under the first regime specification.

In the case of the Italian bond yields, again the spread between the Bund and OAT affects the dependent variable's short-run dynamics significantly. Additionally, its own spread with the Bund is a significant factor in movements in the Italian bond yields.

However, as in the case of the Treasury, non-adjustment effects are indicated, a finding that we deem to provide support for the characterisation of the Italian bond as a 'high-yielders' benchmark', as it is known in the empirical literature (Lane, 2006).

The MS-VECM formulation permits the specification of a further differentiation in the patterns of the underlying relations after 1999, as compared to the first regime. As reported in the second half of Table 4, the cointegration space exercises much more significant adjustment dynamics under the second regime. Especially important are the spreads between the Bund and the Italian bond and the spread between the Bund and the Dutch bond. Additionally, the spread between the Bund and the Treasury appears to exercise no effect on the dynamic adjustment of the system. Last but not least, the similarity of the adjustment coefficients of the European benchmark bonds clearly indicates the close interactions among these variables in the second regime. Overall, the regime shift captures the enhanced linkages among the European bonds in the post-1999 period. This finding complies with results provided by Christiansen (2007), reporting that the European bond markets experienced a loosening of the spill-over effects exercised by the US market, after the introduction of euro. Finally, the direct effects stemming from the French bond towards the rest of the system variables is in line with the literature arguing for the dominant position of this bond in European bond markets (see Dunne *et al.,* 2002 and 2007*)*. However, according to von Hagen and Frattianni (1990) the direction of the interactions, while being necessary, does not stand as a sufficient condition in order to allow the OAT to be characterised as the benchmark for the system.

In order to investigate the question of which variable is the main source of variation in the system, we provide a variance decomposition analysis of the underlying time series of the system in both regimes. The endogenous variables are ordered in such a way that a disturbance to a variable has contemporaneous effects on the variable itself and on variables ordered below it. At one end we assume that the Treasury yields are exogenous to the rest of the system while at the other the Netherlands bond market is entirely endogenous. Specifically we analyze the movements in each of the underlying variables caused by a shock to the rest of the system's bonds, for a period up to 12 months. The results are illustrated in Figure 3. An important finding revealed by the variance decomposition is the enhancement of the proportion of bond yields variance explained by the OAT movements, during the second regime, at the expense of the Bund and Treasury's explanatory power. This indicates that the significance of the French bond as a source of movements in European bond markets has increased in the period after the unification. This finding is in line with the results reported by Dunne *et al.* (2002), indicating that the French bond holds the benchmark status in euro area bond markets, in contrast to the general belief of the market. Additionally, the effects exercised by the Italian bond are sustained and increased in the second regime, a finding that could well support the argument that the Italian bond has a significant weight in Europe's bond markets as the benchmark of the high-yielders.

Additionally, as shown in Figure 3, the variances of the Bund, the OAT, the Dutch and, to a lesser extent, the Italian bond are affected mainly by the Bund's movements in the first two months under the second regime. Even the Treasury, is affected first by its own movements, but then by the Bund's movements. Later, in general after the third or fourth month, the OAT's significance as a source of variance of bond yields increases significantly. These effects appear to explain a dominant proportion of the European bonds variations towards the long run (10-12 months). However, the most intriguing finding is the dominant role of the Italian bond in the interim. Although benchmark characteristics for the Italian bond have not yet been reported in the empirical literature, apart from in the high-yielders' segment, this finding is well in line with the Italian market's characteristics. Specifically, the Italian bond has the unique feature of combining a large proportion of the international bond markets liquidity while providing higher yields related to underlying risks, as perceived by markets' participants. These specific features of the Italian bond market have been reported, among others, in Pagano and von Thadden (2004) and Gomez-Puig (2008).

Overall, the most important finding is related to a duality in the dominant features of the sources of movements in the system, according to the time elapsed from the shock. Specifically, it appears that the effects of the French bond on the rest of the system are evident mainly in the long run, thus highlighting the OAT as a 'long-run benchmark' in terms of the time period needed for its movements to be passed to the rest of the system. In this meaning, the Bund could be characterised as a 'short-term benchmark', for all European bonds in the system except the Italian one. Finally, the effects of the Italian bond appear to be maximized in the interim period, about 4-6 months after the initial effect.

Finally, another important finding of the variance decomposition analysis is the elimination of the Treasury's effects on the bonds in the rest of the system, under the second regime formulation. Additionally, the idiosyncratic effects of the first regime, have largely been replaced by homogenous effects exercised by the French, the Italian and the German bonds, at least as far as the European bonds are concerned. The combination of these results indicate increased financial integration in European bond markets together with increased intra-European linkages for the major European bond markets. However, it should be noted that these results cannot be taken as indicative for the remaining European bond markets, as other research has indicated the existence of core and periphery effects (Kiehlborn and Mietzner, 2005) while we have included only the major ('core') markets in our analysis.

## 5. Concluding remarks

In this paper we formulate an empirical framework for estimating the interactions among major international bond markets. Relying on recent advances in econometric methodology, we allow for the underlying market linkages to be subject to regime switching effects. Our findings underline the scope for using a regime switching framework in order to properly capture the underlying interactions between the financial markets under investigation. We find evidence of a regime shift in the underlying interactions between markets, associated with the European monetary unification. Subsequently, we illustrate a complex network of interactions among the bond yields of Germany, France, the Netherlands, Italy and the United States, which clearly indicates that a significantly stronger set of interactions between European bond markets exists in the period after the shift. Finally, a variance decomposition analysis on each one of the two regimes reveals a change in the European bond benchmark status. Specifically, the dominant features of the Bund have diminished in the aftermath of unification, although the results with respect to the benchmark status are conditional on the duration of the effects. Broadly, we argue that the Bund is the immediate benchmark (short-run), the

French OAT is the long-run benchmark, while the significance of the effects stemming from the Italian bond have increased in the interim.

The limitations of the present research are obvious. The data sample's monthly frequency enables policy conclusions to be drawn, but cannot form a basis for an investment strategy. Additionally, we have, intentionally, restricted the analysis to a more European framework, with the only exogenous effects stemming from the market of US Treasuries. As a result, an examination of the interlinkages under the prism of designing an investment strategy or applying the described empirical framework to a different set of financial markets both provide fertile ground for future research.

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# Appendix

| Table 1: Unit root and stationarity tests | | | | |
|---|---|---|---|---|
| Variables | Unit root tests | | | Stationarity tests |
| | ADF | DF-GLS | PP-GLS | KPSS |
| $DE_{10y}$ | -1.854** | 0.472** | -0.123** | 0.949 |
| $FR_{10y}$ | -1.775** | 0.465** | 0.287** | 1.128 |
| $IT_{10y}$ | -1.541** | 0.619** | 0.033** | 2.392 |
| $NT_{10y}$ | -2.168** | 0.549** | -0.268** | 0.819 |
| $US_{10y}$ | -2.970** | 2.157** | -1.565** | 0.433 |

Note: ** Denote significance in a 1% according to critical values for ADF, DF-GLS, PP-GLS and KPSS tests (formulated by Dickey and Fuller, 1981, Elliott *et al.*, 1996, Ng and Perron, 2001 and Kwiatkowski *et al.*, 1992 , respectively).

Table 2: Johansen's Cointegration Analysis

| p-r | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| r | 0 | 1 | 2 | 3 | 4 |
| $\lambda$-trace | 132.69 | 79.99 | 46.24 | 22.22 | 4.64** |

| LR Exclusion Tests $(H_0 : \beta_i = 0)$ | | $DE_{10y}$ | $FR_{10y}$ | $IT_{10y}$ | $NT_{10y}$ | $US_{10y}$ |
|---|---|---|---|---|---|---|
| | LR | 35.28 | 44.30 | 44.38 | 43.83 | 17.94 |
| | p-value | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | $DE_{10y}$ | $FR_{10y}$ | $IT_{10y}$ | $NT_{10y}$ | $US_{10y}$ | $\mu$ |
|---|---|---|---|---|---|---|---|
| Decomposition of the equilibrium relations | $\beta_1$ | 1 | 1.355 | -0.238 | -1.978 | -0.003 | -0.466 |
| | $\beta_2$ | 1 | -0.414 | 0.039 | -0.648 | -0.006 | 0.202 |
| | $\beta_3$ | 1 | 0.298 | -0.108 | -0.692 | -0.474 | 0.205 |
| | $\beta_4$ | 1 | -1.362 | -0.253 | 1.263 | -0.086 | -2.301 |
| The common trend | | -0.720 | -0.806 | -1.795 | -0.699 | -0.597 | - |

| Restrictions in the long-run structure | | | | | |
|---|---|---|---|---|---|
| | $\beta_1$ | $DE_{10y} - 0.886 \cdot FR_{10y} - 0.422$ | LR-Test: | $X^2$ (1) | 3.92 |
| | $\beta_2$ | $DE_{10y} - NT_{10y} + 0.061$ | | | |
| | $\beta_3$ | $DE_{10y} - 1.174 \cdot US_{10y} + 1.351$ | | p-value | 0.05 |
| | $\beta_4$ | $DE_{10y} - 0.433 \cdot IT_{10y} - 2.276$ | | | |
| | $\beta_1$ | $DE_{10y} - FR_{10y} + 0.141$ | LR-Test: | $X^2$ (3) | 9.53 |
| | $\beta_2$ | $DE_{10y} - NT_{10y} + 0.068$ | | | |
| | $\beta_3$ | $DE_{10y} - US_{10y} + 0.443$ | | p-value | 0.02 |
| | $\beta_4$ | $DE_{10y} - 0.633 \cdot IT_{10y} - 1.132$ | | | |

| Diagnostics (model (2) with *l=2*) | | L-B(44) | LM(1) | LM(4) |
|---|---|---|---|---|
| | $X^2$ | 1132.540 | 60.406 | 26.196 |
| | p-value | 0.05 | 0.00 | 0.40 |

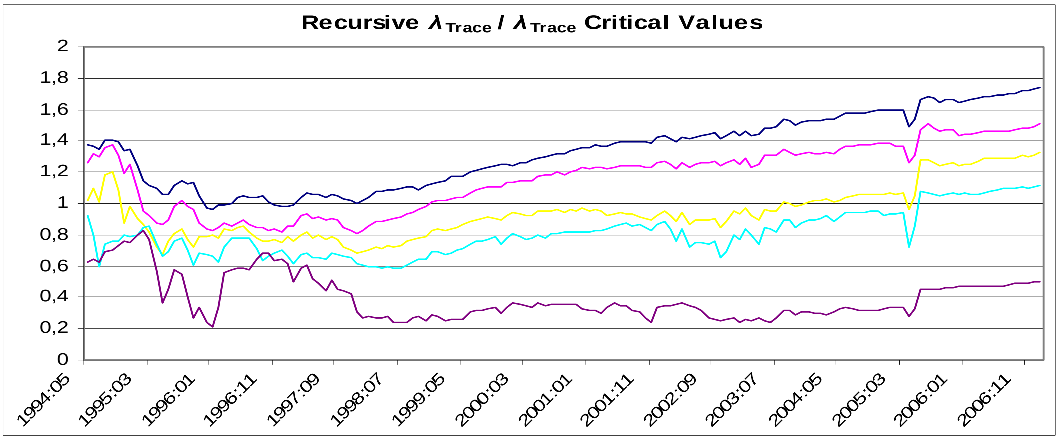
Note : **Denotes significance on a 5% c.i. according to critical values from Osterwald-Lennum (1992) and McKinnon et al. (1999)

| Table 3: The MS-VECM Properties | | | | | | |
|---|---|---|---|---|---|---|
| Transition probabilities | | Regime 1 | Regime 2 | | Regime 1 | Regime 2 |
| | Reg. 1 | 0.9716 | 0.0284 | Duration | 35.2 | 107.32 |
| | Reg. 2 | 0.003 | 0.997 | Prob. | 0.257 | 0.743 |
| Diagnostics | | Linear Model | | Markov Switching Model | | |
| | AIC | -7.633 | | -10.774 | | |
| | LR : 702.487 | Chi(65) =[0.0000] ** | | Chi(67)=[0.0000] | | |
| $RCM = 100\ K^2 \cdot \frac{1}{T}\sum_{t=1}^{T}\left(\prod_{i=1}^{n} p_i\right)$ | | | | 0 | | |

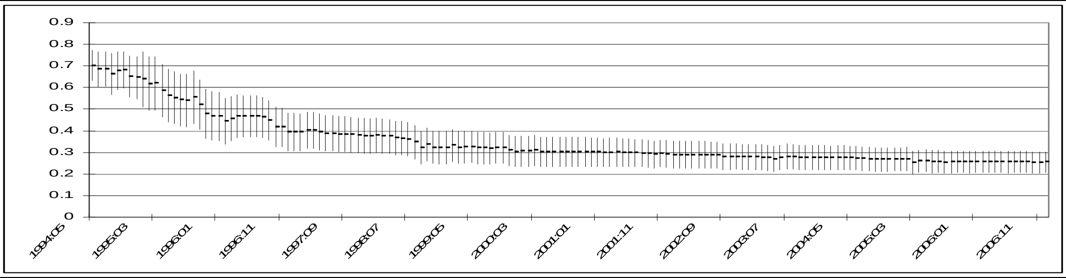
| Table 4: The Short Run (MS-VECM) Relations | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Regime 1 | | | | | | | | | |
| | $DE_{10y}(1)$ | $FR_{10y}(1)$ | $IT_{10y}(1)$ | $NT_{10y}(1)$ | $US_{10y}(1)$ | $\beta_{us\text{-}de}(1)$ | $\beta_{nt\text{-}de}(1)$ | $\beta_{fr\text{-}de}(1)$ | $\beta_{it\text{-}de}(1)$ |
| $DE_{10y}$ | -0.112 | -0.026 | 0.041 | 0.420 | 0.043 | -0.049 | -0.228 | 0.205 | -0.060 |
| $FR_{10y}$ | 0.297 | -0.269 | 0.057 | 0.414 | 0.043 | -0.035 | -0.308 | 0.138 | 0.006 |
| $IT_{10y}$ | -0.172 | -1.081 | 0.241 | 1.310 | 0.092 | 0.057 | 0.450 | **-1.189**** | **0.492**** |
| $NT_{10y}$ | 0.200 | -0.123 | 0.038 | 0.304 | 0.020 | -0.035 | -0.008 | 0.094 | -0.008 |
| $US_{10y}$ | **1.373**** | 0.043 | **0.244**** | -1.034 | 0.081 | **0.155**** | -0.179 | **0.543**** | -0.064 |
| Regime 2 | | | | | | | | | |
| | $DE_{10y}(1)$ | $FR_{10y}(1)$ | $IT_{10y}(1)$ | $NT_{10y}(1)$ | $US_{10y}(1)$ | $\beta_{us\text{-}de}(1)$ | $\beta_{nt\text{-}de}(1)$ | $\beta_{fr\text{-}de}(1)$ | $\beta_{it\text{-}de}(1)$ |
| $DE_{10y}$ | -0.949 | **2.762**** | -0.586 | -0.828 | **-0.117*** | -0.032 | **-1.213**** | 0.346 | **-0.326**** |
| $FR_{10y}$ | -1.126 | **2.853**** | -0.575 | -0.782 | -0.110 | -0.040 | **-1.222**** | 0.553 | **-0.296**** |
| $IT_{10y}$ | -1.294 | **2.529**** | -0.313 | -0.536 | -0.098 | -0.041 | **-1.071**** | 0.337 | **-0.285**** |
| $NT_{10y}$ | -1.087 | **2.755**** | **-0.603**** | -0.655 | **-0.131**** | -0.038 | **-0.908**** | 0.157 | **-0.286**** |
| $US_{10y}$ | 0.032 | 1.091 | -0.862 | 0.932 | **-0.358**** | 0.050 | -0.895 | **1.308**** | **-0.260**** |
| Note: **denotes significance in 5%, *denotes significance in 10% | | | | | | | | | |

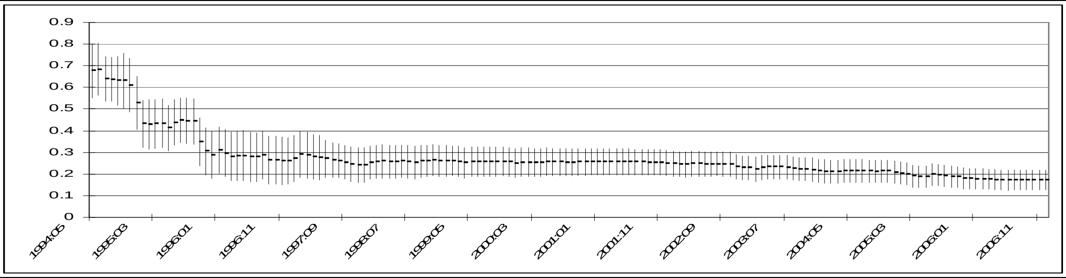
Figure 1: Recursive cointegration analysis

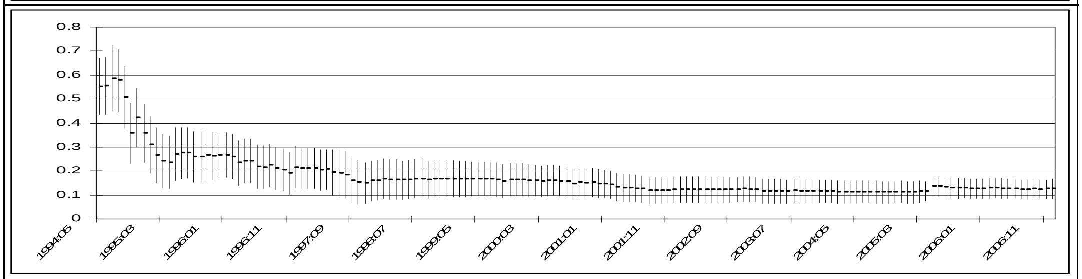
Number of stationary cointegration vectors (1 is the threshold)




Eigenvalues of the cointegration vectors



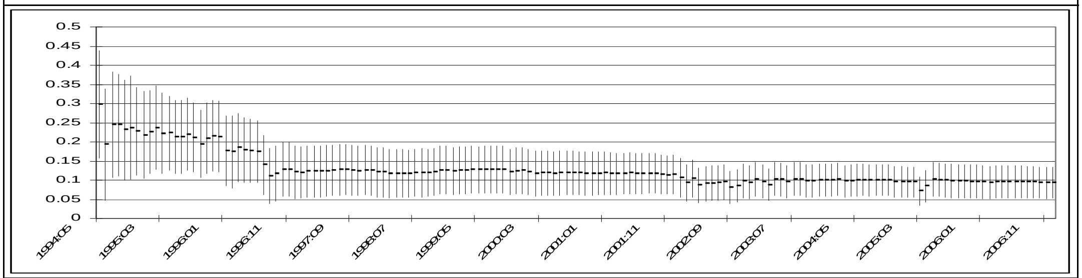



Figure 2: Regime Classification

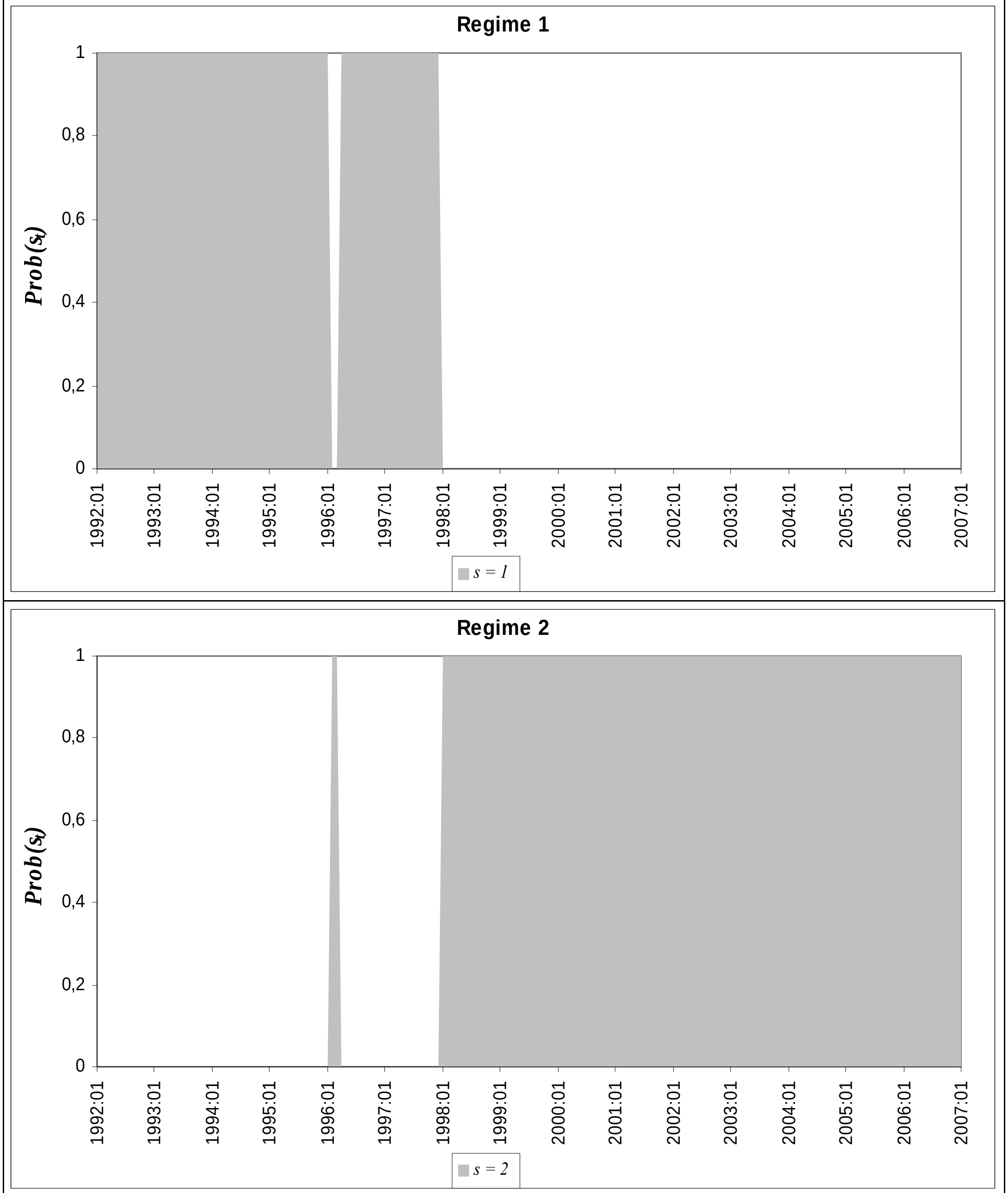


Figure 3a: Variance Decomposition- Regime 1

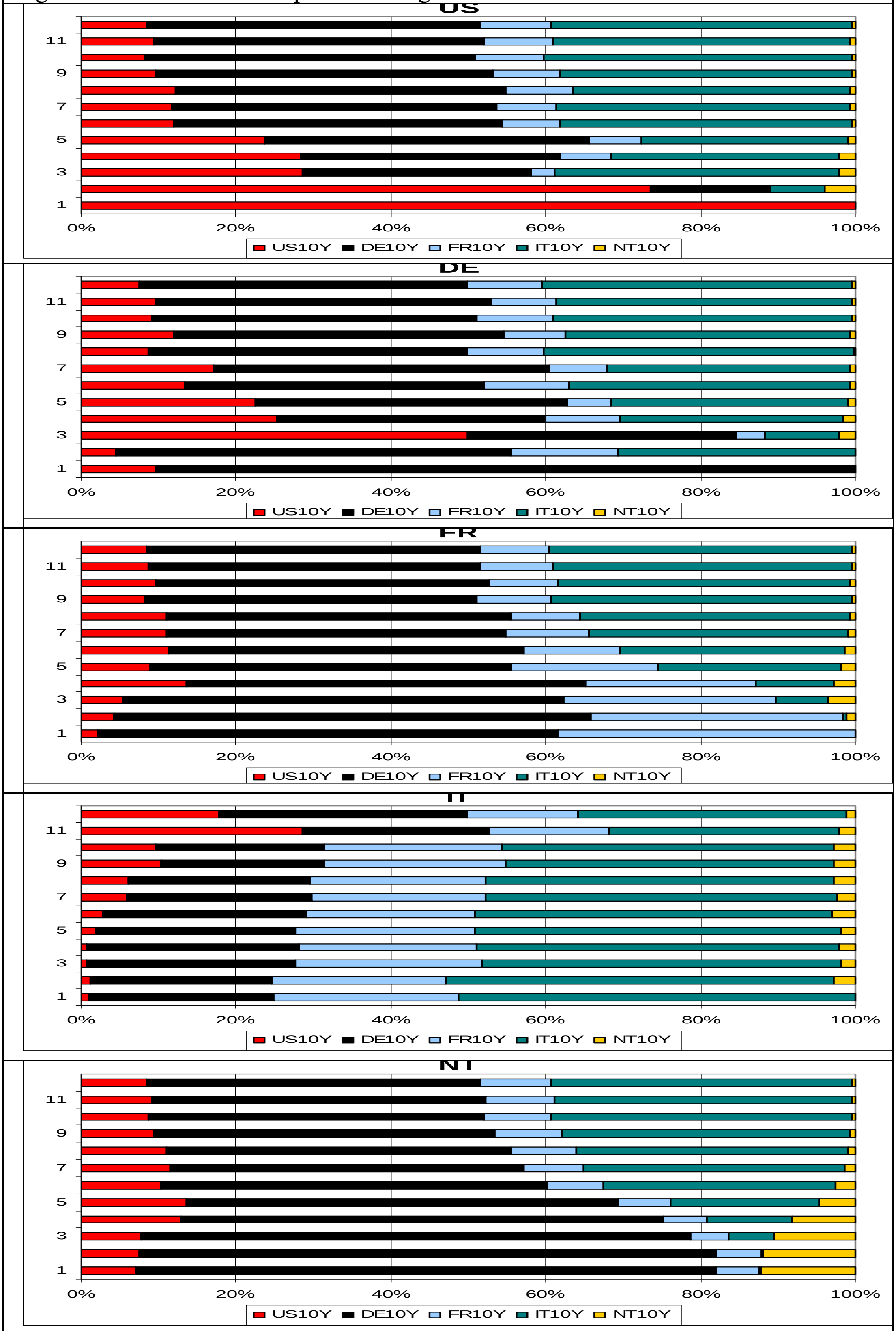
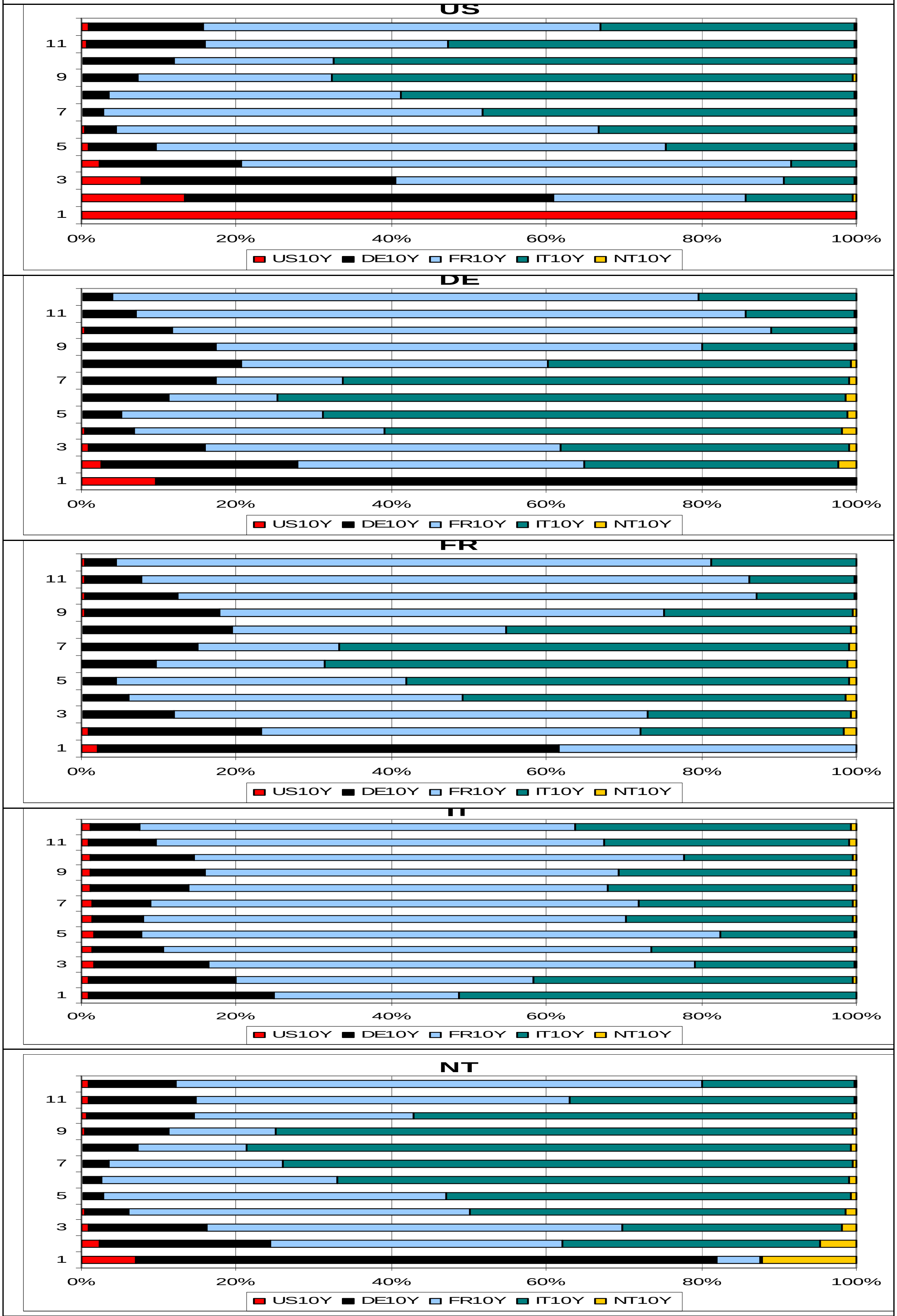


Figure 3b: Variance Decomposition- Regime 2



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