An ever-closer union? Examining the evolution of linkages of European equity markets via minimum spanning trees

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ABSTRACT

The concept of a minimum spanning tree (MST) is used to study the process of comovements for 21 European Union stock market indices. We show how the minimum spanning tree and its related hierarchical tree evolve over time and describe the dynamics. Over the period studied, 1999–2006, the French equity market provides the main linkages in the system. The 2004 Accession states are more loosely connected to the other markets; they form two groupings, with the Czech Republic, Hungary, and Poland having tighter links to the main markets than the remaining Accession markets. Shorter distances between markets indicate a potential reduction of the benefits of international portfolio diversification in European markets, with the possible exception of those markets at the outer limits of the MST.

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1. Introduction

The evolution of the European Union (EU) over the last decade has been marked by such major events as the establishment of the European Monetary Union (EMU), with the introduction of the euro as the single currency for twelve of the EU member states, and an expansion of EU membership in 2004 to include ten new countries, primarily Central and Eastern European (CEE) states. An additional two countries, Romania and Bulgaria, joined the EU at the start of 2007, while Slovenia (2007) and Malta (2008) have adopted the euro. This process of closer economic and financial cooperation has led to increasing levels of financial market integration in the area, as documented in an extensive literature, surveyed in several review studies [1,2]. The effects of these developments on comovements in financial markets are of great importance not only to policymakers but also to investors, because of their potential to affect international asset allocation decisions and diversification benefits. Specifically, the attractiveness of international portfolio diversification will weaken as returns are equalized across countries [3,4].

The present research examines possible effects on the benefits of international portfolio diversification across EU equity markets of both “old” members and “new” Accession countries during the 1999–2006 period. We use a method introduced into the physics literature by Mantegna [5], known as Minimum Spanning Tree (MST) analysis, to examine the extent and evolution of comovements between these EU equity markets. Based on graphing theory, MST analysis provides a parsimonious representation of the network of correlations between markets and is particularly suitable for extracting the most important information concerning linkages when a large number of markets is under examination. A dynamic application allows us to identify the evolution of the patterns of the most important connections between EU equity markets and to examine a number of questions concerning their interrelationships. Which are the “core” EU equity markets? Have
equity market comovements increased substantially due to closer harmonization of economic and fiscal policies associated
with the creation of the EMU? What patterns of linkages can be observed for the Accession members’ equity markets? Our
results indicate increased comovements, identify France rather than Germany as the core market, and describe distinct
patterns of linkages of the new members’ equity markets.

The paper is organized as follows. Section 2 provides a literature review of the MST methodology, which is discussed in
Section 3. The data are described in Section 5 and the conclusions in Section 6.

2. Literature review

Minimum spanning tree analysis has been applied previously to study the clustering behavior of individual stocks within
a single country, usually the US [6–9]. These studies typically find a strong correspondence between business sector and tree
structure, illustrating the ability of the MST methodology to convey meaningful economic information. While these are static
approaches, a variety of dynamic MST analyses of the time-varying behavior of stocks has also been developed and applied in
Refs. [10–15]. MST analysis has also been applied to the foreign exchange markets as a means to trace the dynamics of
relationships between currencies [16].

To date only two studies have been published applying the MST approach to groups of national equity markets. A simple
dynamic analysis based on partially overlapping windows of indices for 20 countries for the years 1988–1996 finds that
markets group according to a geographical principal, as is also the case for a static examination of 51 world indices for
the years 1996–1999 in the same study [17]. Coelho et al. [18] apply dynamic MST methods to examine the time-varying
behavior of a group of 53 developed and emerging markets over the years 1997–2006. Confirming the earlier evidence of
a geographical organizing principle, this research also finds increasing MST density over time, reflecting higher levels of
comovement of international equity markets.

3. Methodology

As proposed by Mantegna [5], linkages between stock returns can be examined by applying a simple transformation of
the elements of the correlation matrix of returns into distances. A connected graph is constructed in which the “nodes”
correspond to companies (or, as here, stock indices) and the “distances”, or “edges”, between them are obtained from
the appropriate transformation of the correlation coefficients. A minimum spanning tree is generated from the graph by
selecting the most important correlations between the stock or index returns. The MST reduces the information space from
$N(N-1)/2$ separate correlation coefficients to $(N-1)$ linkages, known as tree “edges”, while retaining the salient features
of the system.

Specifically, in this study we calculate the correlation matrix of returns of EU member equity market indices and convert
the correlations $\rho_{ij}$ to a distance metric $d_{ij}$ between each pair of stock indices as follows:

$$d_{ij} = \sqrt{2(1 - \rho_{ij})}.$$  \hfill (1)

This forms an $N \times N$ distance matrix $D$. The distances $d_{ij}$ vary from 0 to 2, while correlations run from $-1$ to $+1$. High
correlations correspond to small values of $d_{ij}$. This distance matrix is then used to construct the MST.

The MST is built up by linking all the $N$ elements of the set together in a graph characterized by a minimal distance
between nodes (indices). One starts with the pair of elements with the shortest distance (highest correlation). Next, the
second-smallest distance is identified and added to the MST. Successive equity markets are added, with the condition that
no closed loops are created. The MST is thus a simply connected graph that links all $N$ nodes of the graph with $N - 1$ edges
such that the sum of all edge weights is a minimum. A static picture of index linkages can be obtained from including the
entire data set in a single MST.

In addition to the MST we construct a hierarchical tree to further explore the relationships between the markets. The
MST provides the information needed for calculating the subdominant ultrametric distance matrix $D^\ast$, which is used to
construct the hierarchical tree. The $D^\ast$ matrix is obtained by defining the distance $d_{ij}^\ast$ between $i$ and $j$ as the maximum of
any Euclidean distance $d_{ik}$ determined by moving in single steps from $i$ to $j$ through the shortest path connecting $i$ and $j$ in
the MST. (For a fuller technical discussion see Mantegna [5].) The hierarchical tree ranks the linkages between markets via
the subdominant ultrametric distance, beginning with the pair exhibiting the shortest distance measure. Successive markets
are added to the core of this tree in order of increasing distances. Thus, the last markets added to the hierarchical tree are
those with the most distant linkages to the “core” market(s).

Several additional tools can be used to further explore the dynamics of the system of EU equity markets. The first two
moments of the mean correlations $\rho_{ij}$ and of the distances $d_{ij}$ can be presented in rolling-window graphs. The mean
correlation coefficient is:

$$\rho = \frac{2}{N(N-1)} \sum_{i<j} \rho_{ij}$$ \hfill (2)

and its variance is given as

$$\lambda_2 = \frac{2}{N(N-1)} \sum_{i<j} (\rho_{ij} - \rho)^2.$$ \hfill (3)
As defined in Onnela et al. [12], the moments of the distances $d_{i,j}$ in the MST can similarly be calculated over time in terms of the normalized tree length

$$L = \frac{1}{(N-1)} \times \sum_{d_{i,j} \in \Theta} d_{i,j}$$

(4)

where $N-1$ is the number of edges in the MST. The variance of the normalized tree length is

$$v_2 = \frac{1}{(N-1)} \times \sum_{d_{i,j} \in \Theta} (d_{i,j} - L)^2.$$  

(5)

Changes in the spread of the MST over time can be evaluated through calculation of the mean occupation layer, defined in Onnela et al. [12]:

$$l(t, v_c) = \frac{1}{N} \times \sum_{i=1}^{N} L(v_i^t)$$

(6)

where $L(v_i^t)$ denotes the level of a node, $v_i^t$, in relation to the central node, $v_c$, whose level is defined as zero. The central node can be defined as the node with the highest number of links or as the node with the highest sum of correlations of its links. This concept thus measures changes in the average closeness of markets over time.

Finally, the persistence of links over time is examined by calculating survival rates of links in successive MST. As defined by Onnela et al. [12], the single-step survival rate is the fraction of links found in two consecutive MST at times $t$ and $t-1$:

$$\sigma_t = \frac{1}{N-1} \times |E_t \cap E_{t-1}|$$

(7)

where $E_t$ is the set of links of the MST at time $t$, $\cap$ is the intersection operator, and $\ldots$ gives the number of elements in the set. This is a measure of short-term stability in the system of markets. A multi-step survival ratio is used to study the longer-term stability:

$$\sigma_{t,k} = \frac{1}{N-1} \times |E_t \cap E_{t-1} \cap \cdots \cap E_{t-k+1} \cap E_{t-k}|.$$  

(8)

4. Data

We analyze the returns on 21 EU countries’ equity markets for the period January 1, 1999, through December 31, 2006. Fourteen “older” members of the EU, excepting Luxembourg, are included. Of these fourteen, eleven are members of the EMU; Denmark, Sweden, and the United Kingdom opted out of the common currency. Seven of the ten 2004 “Accession” countries are also included in the analysis: Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Poland, and Slovenia. Data availability and quality preclude covering all ten. All new members are obligated to eventually adopt the euro as their currency. Morgan Stanley Capital International (MSCI) daily closing prices are used for the older EU members, while the data for the Accession countries are from HSBC Bank. These indices are capitalization-weighted indices, reweighted on an annual basis; for details see Ref. [19]. The reliance on standardized indices allows for confidence in the findings, as these indices are designed explicitly to allow for cross-market consideration of returns by investors. By contrast, studies that rely on indices from the individual equity markets run the risk of noncomparability due to differences in construction, coverage, and completeness. All series are expressed in US dollars, reflecting the position of a fully hedged investor outside the area under investigation. The 21 countries in the study and their respective symbols are given in Table 1; summary statistics for each equity market are provided in Table 2. As is typical of emerging markets, the Accession countries generally exhibit relatively high mean returns (exception: Cyprus) but also higher variability than the more developed markets. The Jareque–Bera statistic measures skewness and kurtosis compared to a normal distribution. Normality is rejected (probability of null hypothesis $= 0.00$) in all cases.

An issue that needs to be addressed is the nonsynchronous nature of the data. Recent research suggests that the use of daily data may lead to significant underestimation of equity market integration [20]. Consequently, the daily index level data were converted to weekly (Wednesday) returns: $R_{t,i} = \ln(P_{t,i}/P_{t-1,i})$, where $P_{t,i}$ is the closing price of index $i$ at time $t$. The weekly series contain 417 observations.

5. Results

A number of observations about the linkages between the EU equity markets can be made from examining the MSTs and their hierarchical trees. Fig. 1a contains a static MST for the entire 1999–2006 period, while Fig. 1b is the corresponding hierarchical tree representation of the linkages. We also explore the dynamical evolution of linkages over time by breaking the data down into three segments of roughly similar size, based on significant events in EU history. The initial period,
Fig. 1. (a) Minimum spanning tree for 1999 through 2006 (417 weeks) for 14 “old” European Union country equity markets (coded with black circles), plus 7 Accession members (coded with white diamonds). The centrality of France, which has the largest number of other markets linking directly to it, is apparent. (b) Hierarchical tree constructed from the subdominant ultrametric space associated with the MST. Each vertical line refers to an equity market index; the height of the horizontal line indicates the ultrametric distance at which the market joins the tree.

Table 1
Countries and respective symbol

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Country</th>
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<tbody>
<tr>
<td>AUT</td>
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<td>Denmark</td>
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<td>Italy</td>
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<td>POL</td>
<td>Poland</td>
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<tr>
<td>SVN</td>
<td>Slovenia</td>
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</table>
Fig. 2. (a) Minimum spanning tree for 1999 (156 weeks) through 2001 for 14 European Union country equity markets, plus 7 candidates for Accession to the EU. France, with the most direct linkages, is the central market in this system. (b) Hierarchical tree constructed from the subdominant ultrametric space associated with the MST, 1999 through 2001. France, together with Germany, forms the basis of this hierarchical tree.

Table 2
Descriptive statistics: Weekly return series January 1999 through December 2006

<table>
<thead>
<tr>
<th>Country</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>Jarque-Bera</th>
<th>Prob.</th>
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<tr>
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</table>
January 1, 1999, to January 1, 2002, covers the adoption of the euro as a unit of account in the EMU and ends with its introduction as the currency in twelve of the EU countries (Fig. 2a and b, respectively). The second period continues to May 1, 2004, the entry date of ten new members into the EU (Fig. 3a and b, respectively), while Fig. 4a and b, respectively, covers the third period [21].

In both the static and the dynamic representations the older EU members form the central linkages, with Accession countries taking positions on the periphery. Interestingly, France, rather than Germany, occupies the position as the “core” market in this system, in the sense that it has the largest number of linkages to other markets (for the 1999–2006 period it has seven links, compared to three for Germany). The related hierarchical tree (Fig. 1b) similarly shows that the French market, together with that of the Netherlands, forms the first linkage in the tree. Not surprisingly, given the importance of its economy, the German market is the next to join. The key position of France has also been observed in an MST analysis of 53 equity markets worldwide for the period 1997–2006 in Ref. [18]. The dynamic representations (Figs. 2–4) describe a trend toward an increasing centrality of the French market with respect to the older EU countries (especially Belgium, Germany, Italy, the Netherlands, and Spain). Possible explanations of this clustering around France include geographical and historical ties, trade patterns, similarities in stock market composition, and the common currency [22]. An analysis of 51 global markets, covering the time period 1996–1999, included these same six markets as among the first sixteen to join a global hierarchical tree, France and Germany being the first two of the sixteen [17]. The centrality of France and this fairly stable grouping of markets is also consistent with a variance decomposition analysis applied in a broad study of EMU markets for 1973–2003 [2].
Given that Germany, due to its economic power, is frequently assumed to be the key, or benchmark, country in the EU and in the Eurozone for economic and financial studies, we decided to compare our findings for 1999–2006 with an earlier period, 1996–1999. Here only the 14 older EU members were included, because of data reliability issues. For that period Germany was indeed central to the structure of the MST (results not shown). The differences in these periods point to a relative change in the centrality of the French and German equity markets, implying that in recent years France has become a more representative benchmark, at least for equity market studies.

Much of the other clustering behavior on the MSTs appears also to be explainable by geographical proximity and historical and economic ties, e.g., Spain and Portugal, Belgium and the Netherlands, Finland and Sweden, Greece and Cyprus. An exception is Ireland. Rather than being closely linked to the UK, as might be expected, it usually joins the MST via Germany. Use of the euro by the EMU members eliminates currency risk for investors across that set of countries, removing one reason for the divergence of returns on financial assets. Currency risk appears, however, to be a relatively minor consideration for investors in the developed European equity markets, since Denmark, Sweden, and the United Kingdom remain closely linked to the central node in the system throughout the period under study.

The Accession countries are the last to link into the European markets when we look at the time period as a whole (Fig. 1b). The dynamic process (Figs. 2–4) reveals an evolution from a number of scattered clusters on the MSTs during the pre-Accession period (Figs. 2 and 3) into a more coherent grouping that joins the six CEE Accession members to the developed markets through Austria (Fig. 4). This evolution may reflect an impact of similar policy adjustments required for Accession on financial markets, increasing their degree of financial integration, as well as the importance of the Austrian market in the CEE region. Cyprus consistently links to Greece.

A breakdown of the Accession members into two groups is also apparent in the dynamic analysis. The Czech Republic, Hungary, and Poland, which have the largest and most developed economies, link to each other and join the trees ahead of the remaining four countries (with the exception of Slovenia in the 2002–2004 period). They also precede several of the older EU and EMU members in the first and third subperiods. Cyprus, Estonia, Latvia, and Slovenia are generally the last to join. This two-tier behavior by CEE markets has also been observed in other recent research using a different methodology [23].
Progress toward full EMU membership does not seem to explain the relative positions of these two groups of Accession states. Of the second group, all except Cyprus have made notable progress toward the common currency. Estonia and Latvia are currently in an exchange mechanism, ERMII, a prerequisite for introducing the euro; Slovenia completed this process and adopted the euro on January 1, 2007. In contrast, the Czech Republic, Hungary, and Poland remain further from the goal of the common currency. Once again, reduction of exchange-rate risk for investors appears not to be a dominant factor in increasing equity market comovement in the European context.

The MSTs and hierarchical trees can be used to provide some information relevant to portfolio diversification. Usually located at the outer fringes of the MSTs, Cyprus, Estonia, Latvia, and Slovenia are likely to offer the best diversification opportunities. While they have higher measured risk (standard deviation) than most of the other markets, the relevant element is the marginal covariance they contribute to the portfolio. Higher risk but a lower correlation is of potential benefit if, as is the case here, the higher risk element also generally gives a higher return.

Examination of the means and dispersions of the correlations and distances between the equity markets provides some additional information concerning the evolution of their comovements. Figs. 5 and 6 represent rolling-window graphs of the first two moments of the mean correlations and of the distances $d_{ij}$, respectively, where the window length is 52 weeks and the window step length is 4 weeks. The correlation moments are calculated from the full set of $N(N-1)/2$ correlations for the 21 markets, while the distance measure moments are calculated from the $N-1$ most important linkages. The mean distances are strongly negatively correlated ($-0.967$) with the mean correlations, again demonstrating the ability of the MST as a strongly reduced representation of the entire correlation matrix to convey relevant market information.

In Fig. 5 the mean correlations for the period as a whole show an overall upward tendency (and a corresponding downward movement in mean distances for the MST in Fig. 6), which also characterizes equity markets globally (e.g. Ref. [18]). The main break in this pattern occurs during the second half of 2003, when correlations fall steeply (and distances rise). By early 2004 a reversal begins and correlations and distances return to previous levels by mid 2004. The drop reflects...
Fig. 6. Mean and standard deviation of normalized tree lengths (distances) of 21 EU equity markets as a function of time. The rolling-window length is 52 weeks, with a window step length of 4 weeks. The results are plotted according to the end date of the window.

the uneven pattern of recovery of EU equity markets from a major downturn early in the decade; several of the CEE markets, such as those of the Czech Republic and Hungary, recovered relatively early, while others, such as the German market, lagged. The resumption of a pattern of increasing correlations (decreasing distances) beginning early 2004 may be explained largely by a broadening market recovery but also by the imminent absorption of the Accession countries into the EU. A relatively sharp increase in correlations (decrease in distances) occurs in May 2004, the Accession month. The other fairly abrupt shift in the overall pattern appears in May–June 2006, with a marked increase in correlations and fall in distances, when there was a broad-based but short-lived downturn in equity markets. Volatility, as measured by standard deviations for correlations and distances, showed some tendency to increase through the end of 2003 but reversed this trend subsequently.

Calculations of the mean occupation layer appear in Fig. 7. The node with the highest number of links is selected as the central node; in those cases in which two nodes had the same number of links, the node with the highest sum of correlations of its links was selected. Using these criteria, France is the central node 79.1% of the time, Germany 16.5%, and other countries 4.4%. The mean occupation layer was calculated first using a fixed central node for all windows, France, and then using a continuously updated node. In both cases there is no overall tendency for the mean occupation layer to decrease. This may be due to the continuing pattern of the CEE countries (and frequently Greece) linking only indirectly into the leading EU markets. This contrasts with results in Ref. [18], which showed a reduction of the mean occupation layer over time on a global level. However, average mean occupation layers for the EU markets are lower overall than for global markets for the same time periods, showing that the European system was already comparatively closely grouped around its central node.

Fig. 8a presents the single-step survival rate for the MST. The average is 0.74, indicating that a substantial majority of links survives from one window to the next. In contrast the multi-step survival rate (Fig. 8b) dropped rapidly to a very small number and to zero after 47 months. These results may, however, be somewhat misleading, as shifts in linkages often take place within small groups of countries. Thus, markets appearing in the first third of linkages (seven) include France, Germany, Italy, the Netherlands, and Spain for the entire period under study. Similarly, a set of four countries (Cyprus, Estonia, Latvia, and Slovenia) has been the last to link into the system in recent years. This consistency is useful for international investors,
Fig. 7. Plot of mean occupation layer as function of time. The rolling-window length is 52 weeks, with a window step length of 4 weeks. The black line shows a static central vertex (France), while the black dots use a dynamic central vertex based on the maximum number of links.

Fig. 8. (a) Single-step survival ratio as function of time. The rolling-window length is 52 weeks, with a window step length of 4 weeks. (b) Multiple-step survival ratio as function of time. The rolling-window length is 52 weeks, with a window step length of 4 weeks.
since diversification benefits are potentially lowest on a continuing basis in the first group of countries and highest in the latter, with the other CEE markets placing between them. Periodic portfolio rebalancing may thus be less burdensome than implied by the raw survival rates.

6. Conclusions

The MST methodology provides a parsimonious way to examine patterns of linkages between different markets. Applied dynamically, it reveals both consistencies and evolutions in relationships between markets over time. This analysis has allowed us to identify France as the most central market in the system. A small group of “old” EU markets, sharing high levels of development and/or close geographical proximity, has consistently constituted the most tightly linked set of markets. The CEE Accession countries as a group have organized into a pattern of linkage to the older EU markets via Austria post-May 2004. Within that structure they have also been shown to exhibit a persistent tendency to break down into two groupings; the markets of the Czech Republic, Hungary, and Poland have a higher level of comovement with other EU members, while Estonia, Latvia, and Slovenia, along with Cyprus, remain on the fringes of the system. The overall tendency of mean distances in the MST to decrease over time, along with decreasing dispersion, reveals an increase in comovements of these markets. The implication is a likely reduction of country diversification benefits for investors in EU equity markets. Our methodology does, however, also indicate those markets which are the last to link to the core markets. Such markets present a potential for relatively higher diversification benefits within the EU countries.

References

[21] We also conducted the analysis using equal-size windows (139 weeks each). The centrality of France in each subperiod is unaffected. In the first subperiod the only linkage change is that of Ireland to Belgium instead of to Germany; there were two minor changes in order of joining the tree. In the second subperiod the CEE countries are somewhat more scattered in the MST than in Fig. 3a and b. Since the equal-size second window now includes several months more distant from the Accession date, this result probably reinforces the influence of EU events in bringing about the more cohesive alignment of the new members. By coincidence the third equal-size window covers the same period as the May 2004–December 2006 window used for Fig. 4a and b. Results of the equally spaced windows are available on request.
[22] The centrality of France in the MSTs cannot be explained by reference to correlations of the French market with the US equity market (S&P500 index), as correlations for the period are higher for Germany and the US, as well as for Germany and France, than they are for France and the US.