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Total factor productivity growth in European stock exchanges: A non-parametric frontier approach

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Abstract

This paper examines progressive changes in productivity of the European stock exchange industry using non-parametric frontier techniques. Within the framework of Malmquist indices, total factor productivity growth is decomposed into technological progress and technical efficiency change for a balanced panel of all major European stock exchanges over the period 1993–1999. The principal findings indicate an overall rise in productivity over the sample period, which is driven more by technological innovation than by efficiency improvements. According to organisational setup, technological innovation is more pronounced for exchanges with the following characteristics: automation, equity and derivatives trading, for-profit governance structure, large or medium-size capitalised markets. Technological progress can be interpreted as a sign of the dynamic nature of the whole exchange industry, in which stock exchanges take advantage of intense diffusion of new cost-effective technologies and information systems to leverage themselves onto a higher production frontier.

Key words: stock exchanges, productivity, technological progress, Europe

JEL classification numbers: D24, G29, C23, O52

Tuottavuuden kasvu Euroopan osakemarkkinoilla

Suomen Pankin keskustelualoitteita 11/2002

Heiko Schmiedel
Tutkimusosasto

Tiivistelmä

Tässä tutkimuksessa tarkastellaan tuottavuuden kasvua Euroopan osakepörsseissä vuosina 1993–1999 käyttäen hyväksi ei-parametrisoituja reunatekniikoita. Malmquistin indeksien avulla tuottavuuden kasvu jaetaan tekniikan kehitykseen ja teknisen tehokkuuden muutoksiin. Tutkimuksessa osoitetaan, että markkinapaikkojen tuottavuus on kasvanut tutkimusajanjaksolla ja että kasvu perustuu enemmän teknisiin innovaatioihin kuin tehokkuuden parannuksiin. Tekniset innovaatiot ovat yleisiä erityisesti niillä osakemarkkinoilla, jotka ovat keskisuuria tai suuria, pitkälle automatisoituneita, keskittyneitä osake- ja johdannaisten kauppaan ja voittoa tavoittelevia. Tekninen kehitys voidaan nähdä osoituksena osakemarkkinoiden dynaamisesta luonteesta, missä uudet kustannustehokkaat tekniikat ja informaatiojärjestelmät ruokkivat tuottavuuden kasvua.

Asiasanat: osakemarkkinat, tuottavuus, teknologian kehitys, Eurooppa

JEL-luokittelu: D24, G29, C23, O52

Contents

1 Introduction

European stock exchanges experience a period of great und rapid change. Global integration of financial markets, innovations in communication and information technologies, and the launch of the single currency are fundamental forces that trigged far-reaching transformations of the stock exchange industry in Europe over recent years. Therefore, several stock exchanges are devising strategic responses in a number of directions in order to meet investors' demands of lower trading costs, improved liquidity and immediate access to international trading. These include changes in their organizational governance, improvements in trading services and procedures concerning service quality, staff and new technologies, alliances, implicit mergers, and co-operative agreements. All these trends are visible both in European markets as well as on a global scale (Arnold, Hersch, Mulherin, and Netter (1999), Di Noia (2001a and 2001b), Schmiedel (2001), Hasan, Malkamäki, and Schmiedel (2002)).

The adoption and implementation of new technologies allowing for fully automated securities trading seem to play an important role for the whole industry in this transition period. Exchanges, for example, either established branches with local trading partners using a common technology to access regional markets, formed alliances or implicit mergers with other exchanges, launched hostile take-over bids, or attempted to interconnect leading equity exchanges by the means of a shared common electronic interface. As portrayed in Schmiedel (2001), these strategies led exchanges built up and expand complex networks through interconnected trading places. Essentially, it is widely believed that investments in new electronic trading facilities will yield higher levels of productivity, increased efficiency, and better quality of operation.

Against this background, the present paper attempts to answer the following research questions: the first is whether and to what extent stock exchanges experienced a progress or regress in total factor productivity? Second, what are the real sources of productivity change? Does a catching up process with the efficient benchmark because of changes in pure technical efficiency or scale efficiency primarily drive improvements in the overall productivity? Or is productivity growth of stock exchanges mainly determined by a frontier shift effect stemming from enormous resources spent on new technologies over the last years?

Domowitz and Steil (1999) and Williamson (1999) argue from a supply-sided perspective that exchanges nowadays perform increasingly more like operative firms and that advances in automation of trading has become a crucial factor of structural changes in stock markets that helped to reduce the costs of trading services for the benefits of investors. Hasan and Malkamäki (2001) find economies of scale and scope among exchanges across different regions.

Schmiedel (2001) analyses the performance of European stock exchanges and provides evidence on considerable inefficiencies of individual financial exchanges in Europe. Similar results are found for other countries and regions in Hasan, Malkamäki, and Schmiedel (2002). The next important step in the research agenda involves identification of major factors affecting productivity growth in the stock exchange industry.

Using balanced panel data for a sample of all major European stock exchanges over the period 1993–1999, the primary motivation for this study is to contribute to these debates by evaluating productivity changes at a stock exchanges specific level within a non-parametric multiproduct frontier framework. Malmquist productivity indices capture overall change in total factor productivity. It further allows drawing conclusions about two elements of productivity growth: changes in technical efficiency over time (catching up) and frontier technology shifts over time (innovation) (Färe, Grosskopf, Norris, and Zhang (1994)). That is, an increase in productivity over two subsequent years may be due to higher technical efficiency, technological progress, or a combination of these two components.

In general, the analysis of technical efficiency is an attempt to measure if inputs and outputs are combined in an efficient manner by the production process. However, technical efficiency itself may not adequately solve the issue what actually drives productivity changes for an organization or industry operating in a changing environment where technological change occurs. Hence, it is equally important to study technological progress as another source of productivity improvement. Technological progress causes a shift of the efficient frontier due to new technologies employed by the decision-making unit, and should therefore be distinguished from efficiency improvements by units narrowing the distance towards the frontier. The Malmquist productivity index is often employed in the literature to calculate technological progress and technical efficiency change components (Coelli, Rao, and Battese (1998)).

Although extensive research has been carried out to examine efficiency and productivity changes of financial institutions for different countries, however, little is known about the relative impact of technological change on financial exchanges.[1] This paper continues the research conducted in another study where efficiency scores for European stock exchanges were investigated through stochastic frontier analysis (Schmiedel (2001)). The present study provides a comprehensive analysis of the microstructure of the Euroepan stock exchange industry assuming that exchanges are actually operative firms (Arnold, Hersch, Mulherin, and Netter (1999), Pirrong (1999)). A novum is the application of non-parametric frontier methods to the field of stock exchange research. Importantly,

[1] Berger and Humphrey (1997), and Berger and Mester (1997) survey applications of this literature.

it evaluates efficiency and productivity changes of stock exchanges during the 1993–1999 period using Malmquist productivity indices. The calculation of Malmquist indices provides new insights about the pattern of efficiency gains and the impact of technological innovations on the total performance and production productivity of stock exchanges in Europe. This approach is important for policy formulation so as to anticipate developments in the structure of the trading services industry as exchanges increasingly engage in using new technologies for trading and associated transaction services. Domowitz and Steil (1999) claim that traditional studies on financial markets microstructure mainly focus on the demand side alone that concentrate on explicit trading rules, mechanisms, and on their impact on the price discovery process. To have a better understanding of the functioning of the security trading industry, it is equally important to examine the provision and organization of financial exchange markets from a supply-sided perspective. Thus, there is an obvious need for research in this area.

The principal findings of this paper indicate a rise in total factor productivity in European stock exchange industry during 1993–1999 period. The evidence exhibit that productivity growth is primarily driven by technological progress than improvements in technical efficiency. Related to organizational status and other exchange-specific variables, the results report higher technological progress for exchanges that show characteristics of automation, equity and derivative trading, for-profit governance structure, large and mid-sized capitalized markets.

The paper is structured as follows. The next section reviews studies on stock exchanges and related fields. Section 3 presents a non-parametric frontier framework to calculate Malmquist productivity index and its decompositions. This is followed by a discussion of the data and empirical results. Section 6 comments on policy implications, the role of technology, and future prospects for the sector. Conclusions are given in the final section.

2 Literature review

In a broader context, a number of studies examine important changes in global financial markets evaluating causes, consequences, and future prospects for financial sector consolidation and emphasize the relevance of geographic patterns of financial activities (Berger, Demsetz, and Strahan (1999), The Committee of Wise Men (2000) and (2001), Group of Ten (2001), OECD (2001). In particular, a recent OECD study (2001) describes the forces shaping structural changes in financial markets. The authors anticipate the development towards a future single global market by the means of interconnected national equity markets as a potential outcome of rapidly proceeding market globalization and technological advances. They argue in favor of a remaining coexistence of national local trading places for less-liquid financial products. However, problems may arise as their role is no longer unchallenged by international rival markets and thus the importance of smaller, marketplaces is expected to diminish over time. Similarly, Malkamäki and Topi (1999) stresses driving forces of the changes in the market structures for financial exchanges and securities settlement systems. They argue that economies of scale and scope and network effects will foster cross-border competition among exchanges.

There is only little research available that addresses international comparisons of financial exchanges themselves. In contrast to classical financial market studies, Domowitz and Steil (1999) emphasize important effects of advances in automated trading technologies on operating costs and the organizational structure of an exchange, rather than focusing on transactions costs that traders face. By modeling aspects of the organization of financial exchanges, Pirrong (1999) concludes that the existence of scale economies in the provision of trading infrastructure encourages co-operation and consolidation among financial trading services. Stigler (1961) publishes one of the first studies on scale economies in securities markets followed by a more extensive paper by Doede (1967). These studies report that average operating costs of stock exchanges are a declining function of trading volume. In a closely related study Demsetz (1968) observes that bid-ask spreads are a declining function of the rate of transaction volume. These approaches indicate evidence on economies of scale in exchange operations and in the market making of a particular security, respectively.

Domowitz (1995) argues that common electronic trading platforms, ie implicit mergers between existing exchanges will emerge because of the positive liquidity effect and that such implicit mergers will allow increased revenue as individual exchanges are likely to set prices above marginal cost. In a game-theoretic framework, Di Noia (2001a) addresses possible effects of cross-network externalities on competition and consolidation in the European stock exchange industry. It is demonstrated that competition may lead to inefficient equilibria while an implicit merger may have a Pareto optimal outcome and result in higher profitability of both exchanges. The implicit merger model shows that specialization in listing or trading services among exchanges is likely. By analyzing the effects of U.S. exchange mergers on trading volume and execution costs, Arnold, Hersch, Mulherin, and Netter (1999) find that merging exchanges attracted market share and experienced narrower bid-ask spreads. Recently, Jain (2001) extends the literature using comprehensive multi-country evidence determining the liquidity of stock exchanges as it relates to the institutional design of exchanges. The paper reports lower spreads and volatility by the exchanges that have a hybrid system (includes both trading floor and electronic order book and networks) than totally dealership based systems.

Furthermore, Hasan and Malkamäki (2001) investigate empirically the existence of economies of scale and scope among exchanges providing separate perspectives of different regions. They find evidence indicating substantial higher economies of scale and scope in North American and European exchanges in comparison to Asian and South American exchanges. Comparing descriptive statistics of total costs to total revenues of eleven European stock exchanges over 1993–1994, Cybo-Ottone, Di Noia, and Murgia (2000) observe that efficiency differences are likely to exist across the sample exchanges. The authors do not explicitly compute efficiency effects across stock exchanges. Such an analysis is performed in Schmiedel (2001) and provides evidence on the existence, extent, and explanation of technical efficiency effects of financial exchanges in Europe. Overall cost efficiency scores reveal that European stock exchanges operate on a considerable higher cost level than the efficient benchmark during the 1985–1999 period. Schmiedel (2001) reports further evidence on the importance of exchange-specific factors for the efficient provision of trading services, such as size, institutional design, governance structure, market concentration and quality, and automation of trading. In a subsequent study, Hasan, Malkamäki, and Schmiedel (2002) provide further evidence on cost and revenue efficiency effects from a global perspective. It is found that on average North American exchanges are the most cost and revenue efficient, while European exchanges have improved the most, in respect of cost efficiency. Exchanges in South America and Asia-Pacific regions are found to be lagging in terms of efficiency.

Literature review shows that there does not exist a comprehensive panel based analysis that measures productivity changes in the security industry over time. This paper attempts to fill this gap. Following the basic argument of Arnold, Hersch, Mulherin, and Netter (1999), Pirrong (1999), and Domowitz and Steil (1999), this paper examines changes in the nature of the 'production' process of financial exchanges where exchanges are herein considered as operative firms and thus stresses on the importance and provisions of the supply side of their trading services. The analysis is performed in a multiple input/multiple output framework using a multiyear European data set.

3 Methodology

3.1 Non-parametric frontier models

The two principal concepts used in the literature to measure efficiency are data envelopment analysis, short DEA, and stochastic frontiers analysis, abbreviated SFA. These methods include mathematical programming and econometric estimation techniques respectively. For a parametric approach applied to stock exchanges refer to Schmiedel (2001) and Hasan, Malkamäki, and Schmiedel (2002). The central focus of this study is the application of Malmquist DEA methods to panel data to calculate indices of total factor productivity change, technological change, technical efficiency change and scale efficiency change. Comprehensive reviews of the DEA methodology and applications can be found in Banker, Charnes, and Cooper (1984), Fried, Lovell, and Schmidt (1993), Färe, Grosskopf, and Lovell (1994), Charnes, Cooper, Lewin, and Seiford (1995), and Coelli, Rao, and Battese (1998). An exposition of the DEA technique for generating Malmquist productivity index follows.

DEA is a non-parametric estimation methodology that is usually employed to analyze efficiency and performance of non-profit as well as for-profit entities using inputs to obtain outputs of interest. Within this framework, it is possible to construct a non-parametric piece-wise surface over observations of decision-making units. Efficiency measures are then calculated as deviations of each firm from the efficient frontier. Traditional, total economic efficiency can be decomposed into technical efficiency and allocative efficiency as initially proposed by Farrell (1957). The former refers to the ability of a firm to maximize outputs given a set of inputs. In turn, allocative efficiency pertains the optimal choice of a cost minimizing production plan, given relative input prices and technology. To calculate efficiency measures relative to the benchmark frontier, it is necessary to solve a sequence of linear programming problems.

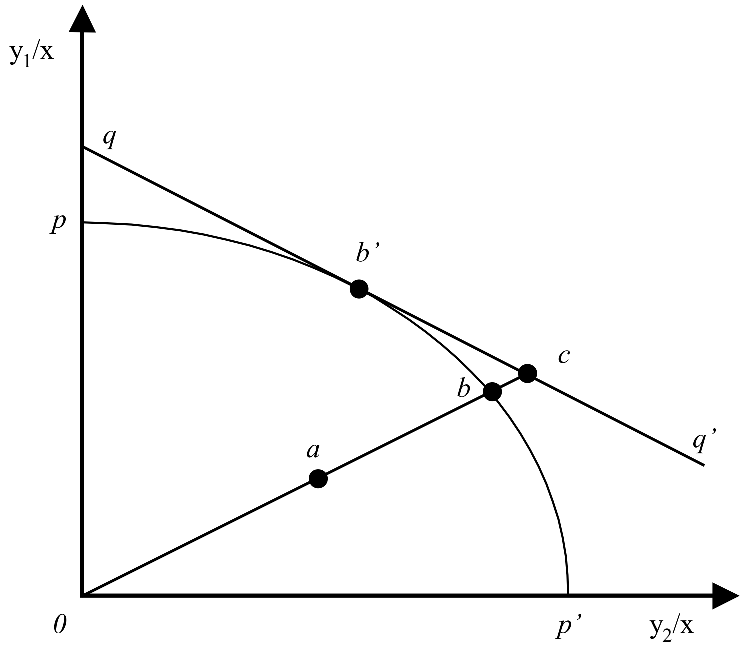
Figure 1 portrays a simple two outputs (y_1 and y_2), single input (x_1) DEA model. The line pp' represents the efficient frontier which envelops all data points. For example, the exchange at point a operates at a technically inefficient level which is captured by the distance between the two production points a and b as measured by the ratio 0a/0b. When price information is available, represented by the isorevenue line, qq', allocative efficiency can be calculated as the ratio 0b/0c. In summary, both measures combined yield overall economic efficiency as presented in equation (3.1)

$$\text{economic efficiency} = \text{allocative efficiency} \times \text{technical efficiency}$$

$$\frac{0a}{0c} = \left[\frac{0b}{0c}\right] \times \left[\frac{0a}{0b}\right] \tag{3.1}$$

Unlike traditional econometric estimation approaches, DEA does not capture explicitly random noise. Thus, DEA attributes all deviations from the estimated benchmark to inefficiencies. Since inputs and outputs are measured in their original units, measurement deficiencies are less likely. Another advantage of DEA is that it does not rely on a predetermined specification of the production frontier.

Figure 1. **Efficient frontier from a two outputs, one input DEA model**



This allows DEA to be flexible enough to address differences in production functions across firms. Furthermore, DEA is free of any behavioral assumption such as cost minimization or profit maximization. It further allows computing efficiency measures when price data is difficult to obtain (Coelli, Rao, and Battese (1998)). Allowing for technical efficiency within a non-parametric framework, Malmquist index approach is used to obtain indication of major sources of productivity losses or gains in European stock exchange industry.

3.2 Malmquist productivity index

The Malmquist index is employed in this analysis to measure stock exchange productivity change as originally formulated by Caves, Christensen, and Diewert (1982). Färe, Grosskopf, Norris, and Zhang (1994) uses DEA-like methods to calculate Malmquist total factor productivity change indices for a sample of OECD countries from 1979–1988. They further illustrate that changes in productivity is the product of changes in efficiency and technological innovation over time. Alternative indices, such as the Fisher (1922) and Tornqvist (1936) indices are found in other studies to examine technical change (Färe, Grosskopf, Norris, and Zhang (1994), Färe, Grosskopf, and Roos (1997), Coelli, Rao, and Battese (1998)). As mentioned in Grifell-Tatjé and Lovell (1996), the Malmquist index is superior in its properties in several aspects relative to the Fisher and Tornqvist indices.

The most notable features of the Malmquist productivity index are that it does not require a priori behavioral assumptions such as profit maximization or cost minimization nor input and output prices. When suitable panel data is available, it permits the researcher to calculate multiple input/multiple output production technologies and to obtain additional decomposition results of changes in technical efficiency and technological change. The Malmquist productivity index is defined by distance functions with respect of two different time periods. An output distance function addresses the maximal proportional expansion feasible without altering the input quantities (Coelli, Rao, and Battese (1998)).[2] The output distance function, d(x,y), takes a value of unity if the observed exchange belongs to the frontier output set and takes a value less than one for exchanges operating below the most feasible production set. Define $x=(x_1,...,x_n)$ and $y=(y_1,...,y_m)$ to be a vector of non-zero inputs and outputs of the i–th exchange in t–th period, respectively. The geometric mean of two productivity indices is taken to compute the Malmquist index, where the first evaluates productivity under the base technology in period t and the second with respect to period t+1 technology. According to Färe, Grosskopf, Norris, and Zhang (1994) the output-oriented Malmquist index, M, between t and t+1 is defined as

$$M(x_{t+1}, y_{t+1}, x_t, y_t) = \left[\frac{d_t(x_{t+1}, y_{t+1})}{d_t(x_t, y_t)} \times \frac{d_{t+1}(x_{t+1}, y_{t+1})}{d_{t+1}(x_t, y_t)} \right]^{1/2} \quad (3.2)$$

Equation (3.3) represents an equivalent way of writing this index

[2] In this paper only output functions are considered. Input distance functions can be used in a similar way and are defined as the minimal proportional reduction of the input vector, given an output vector.

$$M(x_{t+1}, y_{t+1}, x_t, y_t) = \frac{d_{t+1}(x_{t+1}, y_{t+1})}{d_t(x_t, y_t)} \left[\frac{d_t(x_{t+1}, y_{t+1})}{d_{t+1}(x_{t+1}, y_{t+1})} \times \frac{d_t(x_t, y_t)}{d_{t+1}(x_t, y_t)} \right]^{1/2} \tag{3.3}$$

The Malmquist index can be decomposed into technical efficiency change and technological change as follows

$$M(x_{t+1}, y_{t+1}, x_t, y_t) = \text{technical efficiency change} \times \text{technological change} \tag{3.4}$$

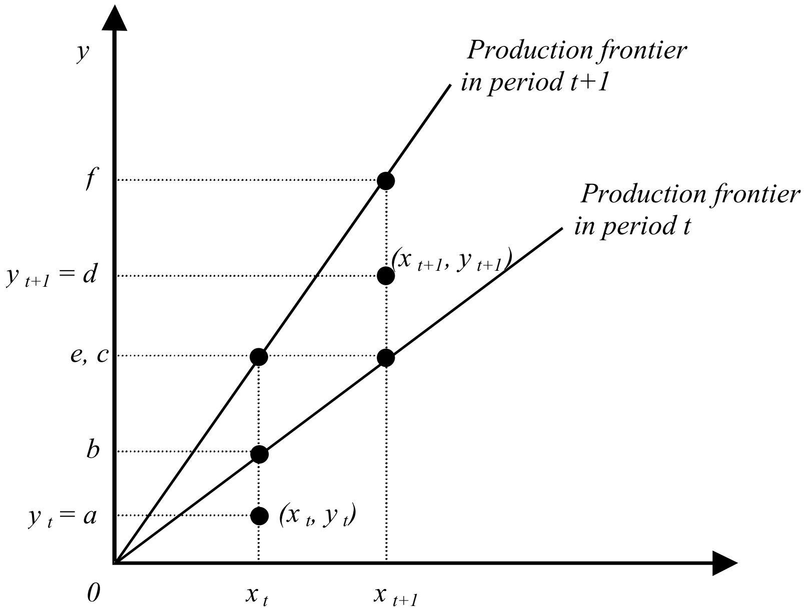
The ratio outside the square brackets captures the efficiency change component and the remaining expression in square brackets measures technological change as depicted in equations (3.5) and (3.6), respectively

$$\text{technical efficiency change} = \frac{d_{t+1}(x_{t+1}, y_{t+1})}{d_t(x_t, y_t)} \tag{3.5}$$

$$\text{technological change} = \left[\frac{d_t(x_{t+1}, y_{t+1},)}{d_{t+1}(x_{t+1}, y_{t+1})} \times \frac{d_t(x_t, y_t)}{d_{t+1}(x_t, y_t)} \right]^{1/2} \tag{3.6}$$

The Malmquist index reveals values greater than unity if improvements in productivity occur. A decline in performance is indicated by a Malmquist index less than one. The same arithmetic holds for each of the components of the Malmquist index. Since the product of the efficiency and technical change defines productivity growth over adjacent time periods, each of these components may show opposite results.

Figure 2. **Malmquist index and productivity changes using constant-returns-to scale technology**



The decomposition of the Malmquist index is portrayed in figure 2 for constant-returns-to-scale technology involving a single input and single output. For example, the production of an exchange, represented by the input/output bundles (x_t, y_t) and (x_{t+1}, y_{t+1}) under each period's production technology, lies below the frontiers of feasible production for these time periods. As the production frontier shifts over adjacent time periods, the Malmquist index reveals productivity growth. According to the above figure, the index decomposition is given in equations (3.7) and (3.8) for a constant-returns-to-scale situation in which technological advances occurs

$$\text{technical efficiency change} = \left(\frac{0d}{0f}\right)\left(\frac{0b}{0a}\right) \tag{3.7}$$

$$\begin{aligned}\text{technological change} &= \left[\frac{(0d/0e)}{(0d/0f)}\frac{(0a/0b)}{(0a/0c)}\right]^{1/2} \\ &= \left[\left(\frac{0f}{0e}\right)\left(\frac{0c}{0b}\right)\right]^{1/2}\end{aligned} \tag{3.8}$$

Computation and decomposition of the Malmquist indices comprise four different functions, $d_t(x_t, y_t)$, $d_t(x_{t+1}, y_{t+1})$, $d_{t+1}(x_t, y_t)$, $d_{t+1}(x_{t+1}, y_{t+1})$. To estimate these frontier functions, DEA-like linear programming method is employed as the most popular technique suggested by Färe, Grosskopf, Norris, and Zhang (1994). Assuming constant returns-to-scale technology, the output-oriented DEA-optimization problems are formulated in equations 3.9–3.12. It should be noted that the distance functions in equations 3.9 and 3.10 include production information and technology each from the same time periods. The other two linear programs compare production points from one period to the reference technology from a different time period. The output-oriented linear programs are as follows

$$\begin{aligned} [d^t(x_t, y_t)]^{-1} &= \max_{\phi,\lambda} \phi \\ \text{s.t.} - \phi y_{i,t} + Y_t\lambda &\geq 0 \\ x_{i,t} - X_t\lambda &\geq 0 \\ \lambda &\geq 0 \end{aligned} \tag{3.9}$$

$$\begin{aligned} [d^{t+1}(x_{t+1}, y_{t+1})]^{-1} &= \max_{\phi,\lambda} \phi \\ \text{s.t.} - \phi y_{i,t+1} + Y_{t+1}\lambda &\geq 0 \\ x_{i,t+1} - X_{t+1}\lambda &\geq 0 \\ \lambda &\geq 0 \end{aligned} \tag{3.10}$$

$$\begin{aligned} [d^{t+1}(x_t, y_t)]^{-1} &= \max_{\phi,\lambda} \phi \\ \text{s.t.} - \phi y_{i,t} + Y_{t+1}\lambda &\geq 0 \\ x_{i,t} - X_{t+1}\lambda &\geq 0 \\ \lambda &\geq 0 \end{aligned} \tag{3.11}$$

$$\begin{aligned} [d^t(x_{t+1}, y_{t+1})]^{-1} &= \max_{\phi,\lambda} \phi \\ \text{s.t.} - \phi y_{i,t+1} + Y_t\lambda &\geq 0 \\ x_{i,t+1} - X_t\lambda &\geq 0 \\ \lambda &\geq 0 \end{aligned} \tag{3.12}$$

where ϕ stands for technical efficiency, λ is a $N\times1$ vector of constants, X and Y represent input and output matrices respectively, and s.t. abbreviates 'subject to'.

This approach can be extended for the variable-returns-to-scale case by further decomposing technical efficiency change into scale efficiency and 'pure' technical efficiency components. The enhanced decomposition can be obtained by expanding the LP's with the convexity constraint $N1'\lambda=1$. In sum, there are $(4\times T-2)\times N$ linear programs to solve for the construction of a chained index (Coelli, Rao, and Battese (1998)). In the case of this study of N=16 individual exchanges across T=8 years, this would involve $(4\times8-2)\times16=480$ linear programs.

4 Data and descriptive statistics

This paper employs data from a variety of sources, including annual reports of European exchanges, various issues of the International Federation of Stock Exchanges (FIBV), IMF International Financial Statistics (IFS), and information from exchanges internet sites. Most of the observations were collected from annual balance sheets, income statement reports, and Internet pages of all major operating stock and derivative exchanges in Europe. In some cases, additional information was obtained from the exchanges by correspondence. Also various issues of the MSCI Handbook served as an important source to obtain additional information on exchange-specific characteristics. Although reporting schemes and information content of the financial accounts vary across time and exchange, however, a consistent balanced panel data set has been constructed including all necessary information on key balance sheet and income statement items for 16 individual exchanges. All national currencies are converted into U.S. $ and are inflation adjusted using data from IFS. The research is designed to follow technical efficiency and technological regress or progress of European stock exchange industry across 1993–1999 (Annual Reports 1993–1999).

Measuring productivity necessitates identification of relevant inputs and outputs. In general, there exist no strong consensus amongst researchers about the specifications of inputs and outputs of any financial institution. Similarly, it is not obvious to determine the relevant market of stock exchanges. The final solution depends on the specific understanding of stock exchange's functioning. In principal, two separate functions can be derived from stock exchanges businesses and their annual reports. First, exchanges facilitate trade processing and matching by providing a centralised trading place or electronic trading systems. Second, financial exchanges are also engaged in the monitoring of listed companies and maintenance of the marketplace attempting to ensure that transactions are fairly and efficiently executed. The output concerning trade processing can be proxied by using trading statistics, namely the number and value of executed trades. Proxies for the output regarding the listing procedure of companies are the number and value of companies listed on a particular exchange.

On the input side, stock exchanges utilize personnel, physical capital including the IT infrastructure, ie computers and software, to maintain the marketplace and to communicate with companies in order to fulfill their listing and monitoring functions. The two most important inputs for stock exchange operations are labor and capital as used in this study. The first input equals the number of full-time equivalent employees on the payroll at the end of each year. The latter is measured as the net asset value of total office premises and equipment. Within this framework, a relatively efficient stock exchange will therefore minimize the level of capital, the number of staff employed, while maximizing outputs in terms of company listings and transactions.

A summary of variable specification and definition is provided in table 1. Table 2 contains descriptive statistics for the input and output variables for each sample year. The means and standard deviations reported in the table suggest that there are substantial variations across the sample with respect to the input and output variables. Examples of other studies where these variables have been used include (Hasan and Malkamäki (2001), Schmiedel (2001), and Hasan, Malkamäki, and Schmiedel (2002).

Table 1. **Variables and definition of in- and outputs**

Variables	Definintion
Inputs	
x_1	Full-time equivalent employees of the i–th exchange in the t–th time period
x_2	Total physical capital of the i–th exchange in the t–th time period (in thousands US $)
Outputs	
y_1	Total number of companies listed on the i–th exchange in the t–th time period
y_2	Total value of shares traded on the i–th exchange in the t–th time period (in millions US $)
y_3	Total number of trades on the i–th exchange in the t–th time period (in hundred thousands)
y_4	Total value of listed companies on the i–th exchange in the t–th time period (in millions US $)

Table 2. **Descriptive statistics of input and output variables, 1993–1999**

Variables	Combined	1993	1994	1995	1996	1997	1998	1999
	Mean [SD]	Mean [SD]	Mean [SD]	Mean [SD]	Mean [SD]	Mean [SD]	Mean [SD]	Mean [SD]
Inputs								
x_1	230.26	193.44	197.06	208.44	228.88	215.38	252.31	316.31
	[223.76]	[256.56]	[243.98]	[242.23]	[227.73]	[175.33]	[187.95]	[238.25]
x_2	29.137	25.602	24.387	23.425	24.555	28.678	34.151	43.160
	[46.920]	[52.550]	[41.211]	[40.045]	[42.584]	[44.789]	[48.175]	[61.285]
Outputs								
y_1	511	482	480	507	531	588	481	506
	[634]	[615]	[587]	[660]	[726]	[811]	[572]	[550]
y_2	306.715	156.191	165.524	172.503	235.525	359.238	473.585	584.436
	[519.187]	[279.836]	[290.931]	[305.707]	[359.280]	[510.866]	[690.906]	[828.201]
y_3	7.684	2.645	3.134	4.186	5.516	8.826	12.050	15.527
	[12.879]	[3.754]	[3.973]	[5.967]	[7.847]	[11.476]	[16.241]	[22.073]
y_4	369.720	239.141	225.764	249.236	303.729	405.374	486.514	678.284
	[504.920]	[345.262]	[316.002]	[356.290]	[393.994]	[494.079]	[581.919]	[794.487]

Note: All currencies are converted to US$ and inflation adjusted. SD stands for 'standard deviation'.

Table 3. **Summary of European stock exchanges in the sample, 1993–1999**

Exchanges	Model I	Model II	Model III
Euronext Amsterdam	X	X	X
Bolsa de Bilbao	X		
Bolsa de Madrid	X	X	X
Euronext Brussels	X		
Copenhagen Stock Exchange	X	X	X
Deutsche Boerse AG	X	X	X
Helsinki Stock Exchange	X	X	X
Istanbul Stock Exchange	X		
London Stock Exchange	X	X	X
Luxembourg Stock Exchange	X		
Oslo Borse	X	X	X
Euronext Paris	X	X	X
OM Stockholm Exchange	X	X	X
Swiss Exchange	X		
Warsaw Stock Exchange	X	X	X
Budapest Stock Exchange	X		

The following models are estimated in this study. Modeling output-oriented Malmquist productivity growth indices, the first estimation includes two outputs, namely the number of listed companies and the total value of trades, and two inputs, labor and physical capital. Model II keeps the same outputs and inputs, however, it concentrates on a fewer number of stock exchanges, as in model III. Additionally, model III considers all four output variables, number of listed companies, value of shares traded, number of trades, value of listed companies, whilst keeping the same inputs as in the other models.[3] All models are estimated for the 1993–1999 sample years.[4] Table 3 summarises all financial exchanges included in models I to III.

5 Empirical results

The above discussed models result the measures of total factor productivity change and its multiplicative composites of efficiency and technological change for the sample period across each year and for exchange-specific variables as well as different organizational designs, types and sizes. The results are reported in the tables 4 to 7. All estimates are reasonably consistent across different model specifications and variations of in-sample exchanges. Recall that the Malmquist index and any of its components with values greater than unity indicate an increase in the relevant performance, whereas values below one signal a drop in exchange performance.

The tables 4 to 6 show mean annual components of the Malmquist productivity index for each of the models for 1994–1999. On average the European stock exchange industry increased total factor productivity about 4.9% to 13% over the sample period depending on the model specification used in the estimation (see bottom row of mean values in tables 4 to 6). This indicates that European stock exchanges performed well in recent years in terms of productivity growth. In respect of annual sector performance, 1997 is associated with the largest rise in productivity. A closer look on the major sources of total factor productivity shows that technological change on average made the largest contribution rather than improvements in efficiency, regardless of model variation. Tracing yearly averages in tables 4 to 6, it is found that in models II and III an overall increase in efficiency change has occurred during the entire period, although model I reveals a marginal loss in technical efficiency. However, the picture becomes clearer when decomposing efficiency change into scale change and pure technical change. In this case, all estimates find on average rising pure technical efficiency of the sector with a highest average score of 2 percent per

[3] Considering additional outputs in model III requires a smaller sample size. Other exchanges could not be included due to missing observations and data availability.

[4] Note that all Malmquist index numbers are measured using an output-oriented approach. Similar results are obtained when modeling input-orientation and are available from the author upon request.

year. Hence, scale deficiencies may explain lower performance of stock exchanges in terms of efficiency change in model I. However, in models II and III scale efficiency appears to be positive with peak scores in 1998.

The results of individual years show evidence that not all observations over the sample years are associated with an increase in pure technical efficiency. Declines in pure technical efficiency should be construed against the background that technical progress might further magnify an observed reduction in pure technical efficiency. One plausible explanation is that pure technical efficiency is calculated against an efficient frontier that represents more advanced production technology. Generally, if the shift of the benchmark frontier, due to an increase in pure technical efficiency, were less than the upward movement of the frontier caused by technological innovation, it would result in an overall regress in pure technical efficiency. Put differently, scale deficiencies are mainly due to poor performances of most exchanges over the entire period, compounded by a considerable frontier shift that many exchanges could not keep pace in terms of adjusting to optimal size.

Figures 3 to 5 provide visual summary of the Malmquist productivity index and its basic components for each model during the 1993–1999 period. Note that 1993 represents the base year and equals the value of one. The graphs indicate that total factor productivity is driven more by technological change than by pure technical efficiency.

Table 4. **Malmquist productivity index summary of annual means (Model I), 1994–1999**

Year	Efficiency change (EFFCH)	Technical change (TECHCH)	Pure technical efficiency (PECH)	Scale efficiency (SECH)	Malmquist index (MALM)
1994	1.346	0.840	1.206	1.116	1.130
1995	1.161	0.919	1.112	1.043	1.066
1996	0.918	1.174	0.991	0.926	1.078
1997	0.869	1.420	0.896	0.970	1.234
1998	0.846	1.076	1.117	0.758	0.910
1999	0.798	1.147	0.844	0.945	0.915
Mean	0.972	1.080	1.020	0.953	1.049

Note: All Malmquist index averages are geometric means.

Table 5. **Malmquist productivity index summary of annual means (Model II), 1994–1999**

Year	Efficiency change (EFFCH)	Technical change (TECHCH)	Pure technical efficiency (PECH)	Scale efficiency (SECH)	Malmquist index (MALM)
1994	1.195	0.950	1.191	1.003	1.136
1995	1.086	0.969	1.066	1.019	1.052
1996	0.934	1.328	1.006	0.928	1.241
1997	0.814	1.723	1.010	0.805	1.402
1998	1.085	0.779	0.780	1.390	0.845
1999	1.029	1.154	1.057	0.974	1.187
Mean	1.016	1.112	1.010	1.006	1.130

Note: All Malmquist index averages are geometric means.

Table 6. **Malmquist productivity index summary of annual means (Model III), 1994–1999**

Year	Efficiency change (EFFCH)	Technical change (TECHCH)	Pure technical efficiency (PECH)	Scale efficiency (SECH)	Malmquist index (MALM)
1994	1.102	0.969	1.119	0.985	1.067
1995	1.221	0.862	1.045	1.169	1.053
1996	0.937	1.207	1.029	0.911	1.130
1997	0.882	1.541	0.951	0.927	1.359
1998	0.996	0.814	0.865	1.152	0.811
1999	0.977	1.089	1.019	0.959	1.064
Mean	1.013	1.055	1.001	1.012	1.069

Note: All Malmquist index averages are geometric means.

Figure 3. **Summary of productivity changes in European stock exchanges industry (Model I), 1993–1999**

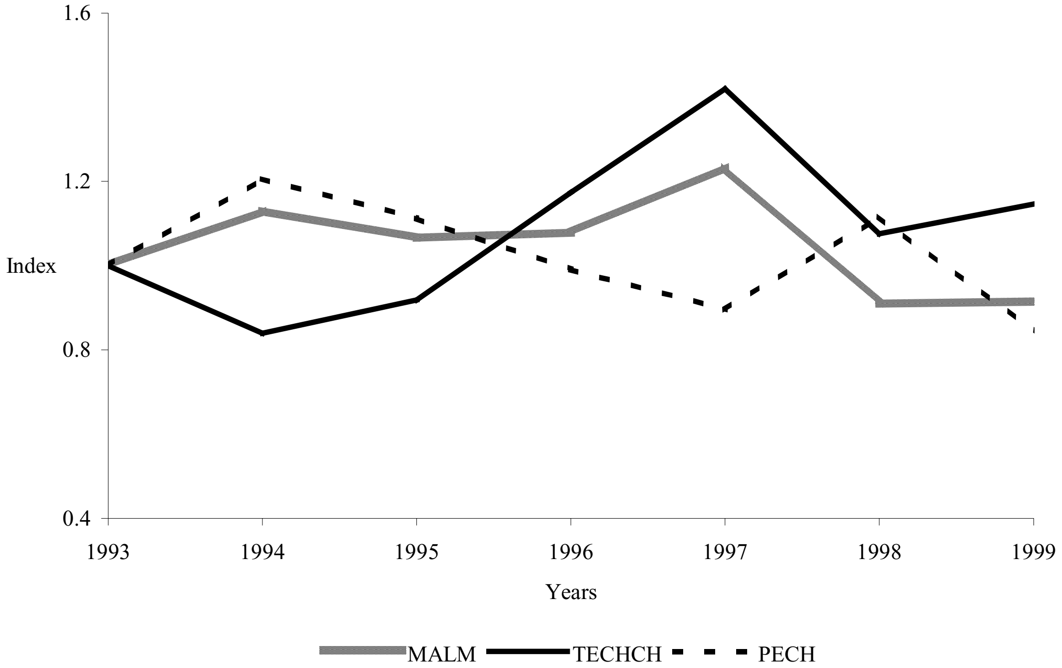


Figure 4. **Summary of productivity changes in European stock exchanges industry (Model II), 1993–1999**

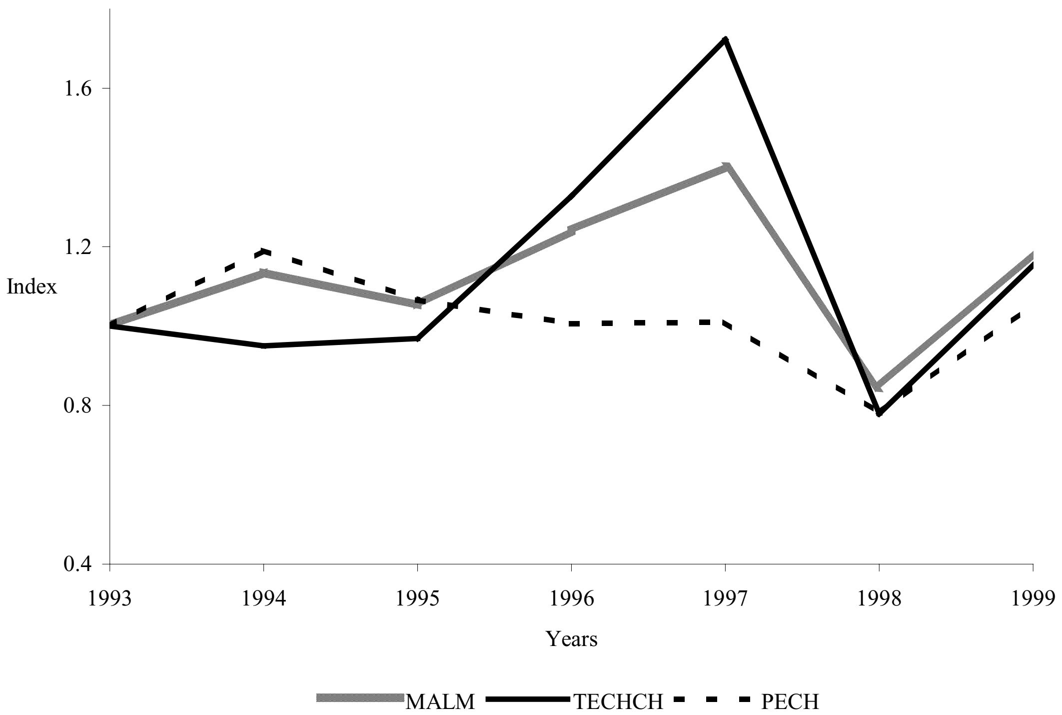
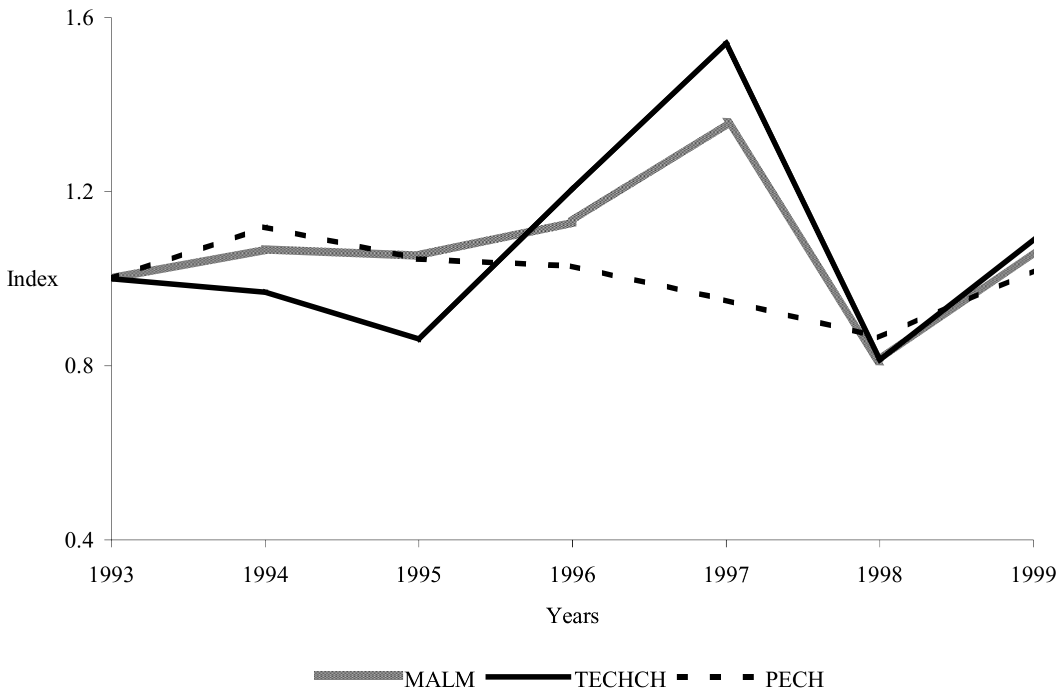


Figure 5. **Summary of productivity changes in European stock exchanges industry (Model III), 1993–1999**



Focusing further on the results reported by model I, the model with the highest number of observations, productivity scores are analyzed by different groups of exchange institutions. These estimates are presented in table 7 for exchange-specific variables as well as different organizational designs, types and sizes. It shows that all types of exchanges reveal an overall rise in productivity. The estimates are also consistent with the previous findings that gains in productivity are rather due to technological innovations than efficiency gains over the sample period. Almost all exchange types have values greater than unity for technological change, except for smaller, less capitalized markets, which remain nearly unchanged.

However, there is some variation in productivity and efficiency across different types and characteristics of stock exchanges over the period under consideration. Controlling for exchange size, larger and mid-sized exchanges in terms of employment and asset size score higher improvements in productivity due to higher technological progress relative to smaller sized exchanges. However, smaller exchanges score higher in efficiency and seem to have adopted good management practices that compensate for size. The results further show that both older and more recently established exchanges have improved productivity over recent years, with average scores of 11.4% and 12.1% respectively. Older exchanges show scores greater than one in each component of the Malmquist index with highest numbers for technological change, whereas more recently established exchanges seem to better achieve optimal scale. Furthermore, the average scores report somewhat higher technological change numbers for automated exchanges over auction type exchanges, whereas auction type exchanges indicate marginal better overall performance.

Table 7. **Malmquist productivity index by size, categorization, organizational form of European stock exchanges (Model I)**

Exchange characteristics and organizational setup	Efficiency change (EFFCH)	Technical change (TECHCH)	Pure technical efficiency (PECH)	Scale efficiency (SECH)	Malmquist index (MALM)
No. employees					
>300	1.024	1.134	1.001	1.033	1.100
100–300	1.041	1.172	0.984	1.081	1.196
0–100	1.041	1.068	0.978	1.052	1.075
Total assets					
>80000	0.933	1.226	0.935	1.001	1.106
40000–80000	1.073	1.111	0.984	1.121	1.160
0–40000	1.088	1.040	1.019	1.058	1.106
Recently established exchanges	1.097	1.054	0.936	1.173	1.121
Older exchanges	1.016	1.138	1.004	1.014	1.114
Auction	1.001	1.167	1.014	1.000	1.108
Automated	0.957	1.170	0.963	0.986	1.093
Equity only exchanges	1.076	1.114	1.009	1.075	1.157
Exchanges with derivatives	0.951	1.122	0.941	1.010	1.029
Cooperative exchanges	1.157	1.033	1.025	1.148	1.137
De-mutualised	0.953	1.174	0.961	0.989	1.101
Top 5 markets	1.001	1.167	1.014	1.000	1.108
Medium markets	0.957	1.170	0.963	0.986	1.093
Smallest markets	1.157	0.999	0.980	1.186	1.133

Note: All currencies are converted to US $ and inflation adjusted.

Exchanges that include only stock trading score higher productivity gains which are mainly due to better efficiency numbers relative to exchanges with derivative trades. However, exchanges that are also active in derivative trading seem to engage more in updating and upgrading their trading technologies, which is supported by the evidence of greater technological progress. The governance structure seems to be important for exchanges decision-making process to adopt new technologies. The results support this view and exhibit higher improvements in technological innovation for profit motivated exchanges over cooperative and non-profit oriented exchanges, however, demutualized exchanges deviate from the optimal scale. Among different groups, according to market capitalization, substantial productivity improvements of 9.3% to 13.3% are associated with higher technological progress for top and medium markets compared to smaller sized markets, while the latter experienced highest gains in scale.

6 Future prospects for policy and market design

Building on the analytical framework presented in the previous sections, this section discusses global issues and concerns for policy and market infrastructure as it regards major developments affecting the European securities markets in the near future.

As financial markets become more integrated, national and regional marketplaces and providers of financial trading services are challenged to maintain existing market share while adjusting to a rapidly changing environment with new competitive norms. Compounding to this global pressure for consolidation advances in technology have caused reduction in communication and transaction costs. A number of exchanges are revising their business strategies and transform governance structures into more profit-oriented businesses aiming to become a listed company themselves. At the same time, additional competitive pressure arises from alternative trading systems attempting to invade exchanges markets by providing alternate liquidity pools. As securities markets evolve, financial regulatory authorities are equally opposed to cope with these trends and to undertake appropriate steps to set up and ensure a stable and favourable regulatory environment.

Against this background, stock exchanges face unique problems with high relevance for the whole industry on an unprecedented and global scale. In the following future outcomes for the trading landscape arising from these restructuring processes are discussed by outlining different strategies available to national and regional stock exchanges as well as to regulatory authorities to meet these challenges.

Regulatory initiatives and arrangements

In the European context, it is widely believed that a number of factors and barriers are significantly preventing progress towards EU cross-border integration of financial markets in a large number of areas. Such factors concern the lack of clear EU regulation, an effective decision making system or common interpretation of rules, differences in legal systems and taxation, political and external trade obstacles, as well as cultural barriers.

In this respect, the recently established Committee of Wise Men, chaired by Baron Alexandre Lamfalussy, was to propose reforms towards a future more homogeneous regulatory environment in EU securities markets that could best respond to market developments (The Committee of Wise Men (2000) and (2001)). The Lamfalussy committee achieved to establish a broad consensus about the priorities to accelerate regulatory progress. This regards the following points: a single prospectus for issuers to facilitate firms' access to capital across Europe; modernization of admission to trading; home country supervision for all wholesale members and more distinct definition of professional investor; adoption of international accounting standards; single passport for recognized stock markets.

As a result, the committee of wise men received a widespread support for a four-stage concept of future financial services legislation. Level 1 contains framework principles determining the essential political direction to be decided by European Parliament and the Council of Ministers on the basis of a proposal by the European Commission. Level 2 foresees the establishment of two new Committees – an EU Securities Committee (ESC) with a primarily regulatory mandate and an EU Securities Regulators Committee (ESCR) with advisory functions – to define, propose and decide on the technical details of implementation of the legislation. The third level encompasses the strengthening of a cooperative network among regulators to ensure common implementation standards. Finally, the Commission is responsible for the enforcement of Community law.

The above outlined views of the Lamfalussy Committee represent an important investigation towards a more efficient EU legislative process in order to create a fully integrated European financial services and capital market. These regulatory initiatives are highly required and reflect a move in the right direction. Nevertheless, there are important limits and one should not overstate this reform proposal, as it would only partially remove obstacles to an integrated European securities market. In particular, it seems to be challenging to find the right balance to divide and to assign responsibilities among the various EU institutions – The Council of Ministers, the Commission, and the new Securities Committees. Unclear competencies among these institutional bodies and inflexible incorporation of the proposed new regulatory committees in the EU apparatus bear the risk of delaying implementation of reforms and at the same time delaying the benefits arising from market integration. Among other suggestions, Murray (2001) rightly points out that it is equally important that the Commission pursues a much more active role in enforcing existing legislation, ie by monitoring those governments that impede single market access. Overall, it would be optimal to establish a new and flexible regulatory framework, allowing Europe to compete effectively in the global arena.

Concentration versus fragmentation

As established in Schmiedel (2001), European stock and derivative exchanges reorganise their businesses and their operations by forming alliances, takeovers, or other forms of cooperation in order to maintain market shares and leverage themselves on a better position vis-à-vis their competitors. In this light, such co-operations among European stock exchanges are mainly motivated by the assumption that trading would be most efficient if trading is centralised not necessarily on a few or eventually on only one physical base. It may be simply a technological agreement between exchanges to use standardized technologies ensuring high compatibility in different or even one centralised trading systems so as to maximise scale economies and improve actively efficiency in the provision of trading services.

Consistently, it is apparent from the findings of this study that technological innovation and creation of networks plays an important role for the future European trading landscape. As Pirrong (1999) claims rapid advances in communications technology have helped to minimise the fragmenting effect of physical distance on exchange formation. Shapiro and Varian (1999) believe that cheap computer technology will make trading via network to dominate business. Network will provide investors with options to choose among alternative preferences. Domowitz and Steil (1999) and Domowitz (1995) state that an exchange or a trading system is analogous to a communication network as the benefit to one trader transacting on a given trading system increases when another trader chooses to transact there as well. In terms of trading volume, the rapid emergence of Eurex is a good example of how networks can replace a trading floor in another country. This effect is called network effects or network externalities.

Economides and Siow (1988) show that liquidity considerations limit the number of markets in a competitive economy. In their spatial competition model with liquidity as a positive externality, they demonstrate that the value of a network increases with the number of users. In other words, there may be too few markets because nobody wants to use a new market with low liquidity. Later, Economides (1993) reveals that networks (such as electronic trading systems) are by their nature self-reinforcing. As a consequence, networks exhibit positive critical mass. A second consequence is that optimality will not result from perfect competition. According to Economides, this opens the possibility that some market structures (such as monopoly), which can co-ordinate expectations, might achieve larger networks and higher welfare than would perfect competition. Network providers have market power through the setting of standards for the network. Stock exchanges usually set rules and regulations on their trading systems. This, according to Economides, impedes technological innovation. This should motivate authorities and the investment community to prohibit the possibility that upcoming alliances operate as a price cartel or misuse their market power to impede competition (Malkamäki (1999)).

Economides (1993) also argues that equilibrium price information from a financial exchange network is another externality, in addition to the market liquidity. A concern here stems from the observation that smaller exchanges are actually cream skimming as some of them concentrate on trades that take advantage of price discovery on a major exchange. It is also seen that realised bid-ask spreads are higher for shares that are subject to cream skimming. Thus the validity of the market price on the bigger exchange seems to be reduced as customers (brokers) switch to alternative networks. The problem of course is that this is not necessarily in the interest of end investors, as the spreads are wider and quality of the market price worse. A solution suggested by Economides is to price market equilibrium information appropriately. This question relates to legislation and interim rules and regulations as well as microstructure of trading systems of stock exchanges and specifically those of alliances.

Currently, the financial market includes network externalities especially in the United States where there has been a huge invasion of new equity routing/matching/trading systems, eg Instinet, Posit, AZ, and Attain etc.[5] Technological innovations considerably reduced set-up and implementation costs for new trading systems, at the same time lowering barriers for new entrants to penetrate the market, while encouraging the construction of novel and sophisticated types of trading system (OECD (2001)). Even though the experience of alternative trading systems is less successful in Europe, these new alternative electronic trading systems create new services and competition that may lead to fragmentation of liquidity and cream skimming, thus posing a major challenge for management of exchanges. On the other hand, it is probably not likely that these systems gain sufficient market share to put to much pressure on exchanges, as they are dependent on the pricing data established on main exchanges. However, all these trends have opened new strategic scenarios in which economies of scale and expectation of further cost efficiency may lead to consolidation or traditional stock exchanges.

[5] For a comprehensive overview on these issues, see Korhonen (2001).

Exchanges' governance structure

Concerning the organizational structure, many exchanges formerly mutual co-operatives transformed their ownership structure into for-profit shareholder-owned corporation. Hart and Moore (1996) argue that in co-operative exchanges members may be reluctant to accept changes that would affect their own business, even if this were in their own interest in the longer run. In other words, it seems that member-owned exchanges with a non-automated trading environment tend to impede the transition to automated and remote membership trading technologies. The success of Eurex relative to LIFFE may be partly explained by differences in the governance of these exchanges.

As competition intensifies there is a clear need for exchanges to behave like for-profit oriented companies to adopt more efficient decision making processes. This includes a direct influence by ownership on the management. At the same time, exchanges are likely to become more flexible to employ appropriate measures to adjust to market developments, to facilitate alignments and cross-border co-operation among exchanges, and to show greater responsibility concerning marketplace maintenance. It can be anticipated that demutualization and privatisation will be a prime prerequisite to be successful in the future. However, as mentioned in Di Noia (2001b), the ownership composition may create many conflicts of interests as the interests of the owners of the exchange may diverge from those of the principal customers of its trading services.

Productivity gains

Further integration of financial markets and technological advances will affect the development of the stock exchange infrastructure. The combined effect of these various forces has created a plausible environment for consolidation in the European securities industry and will have an impact on the nature of the 'production' process of trading service providers. Overall, European stock exchanges seem to operate on a relatively higher cost level than optimal (Schmiedel 2001). Accordingly, a substantial degree of consolidation of exchange industry is likely to take place as less productive or otherwise less successful trading service providers will have to revise their strategies or to quit the business. One possible effect is that by concentrating trading activities on a few exchanges, consolidation might force an exchange to produce the most efficient price-quantity combination. A more cost efficient provision of the supply side of trading services may probably also translate to some degree into less costly trading on the demand side.

In addition, consolidation of the stock exchange industry might also increase overall system efficiency if the remaining exchanges are better able to agree on a high degree of standardization across systems. Consequently, it would be advantageous for cooperating exchanges to share, sometimes high, investment and establishment costs of new trading technologies or networks.

Given the importance of an exchange in the financial and economic system of a country, it seems clear that consolidation will not only have a positive effect on listed companies and investors, but also beneficial for the whole economy.

7 Conclusions

In the light of increasing integration and consolidation in modern global and European financial markets, evolving governance structures, alliances and changing regulatory environment, this paper provides important new evidence on the productivity, performance, and competitiveness of stock exchanges in Europe. Generally, the rapid pace of advances in innovative communication means and new technologies are deemed to be one of the major forces driving recent growth of trading in global financial markets. The potential impact of electronification is important and far-reaching for the whole trading industry. In this scenario, stock exchanges are facing a new dimension of increased competition forcing them to revise their business strategies and to undertake enormous efforts in investment and implementation programs of new technologies in order to cope with these changes and new environment. Although one might anticipate that advances in new technologies have the potential to shape the future trading landscape, however, relatively little is known empirically about the impact that technology has on the production process of the stock exchange industry. Put differently, it is unclear what actually drives productivity changes for the stock exchange industry operating in a changing environment where technological change occurs. It is at heart of this study to evaluate the nature and extent of changes in productivity in European stock exchange industry. Furthermore, this paper examines whether stock exchanges were able to raise productivity rather by a catching up process with the efficient benchmark or by intense investments in updating or upgrading their technologies.

Using balanced 1993–1999 experiences of all major European stock exchanges, this paper traces productivity of stock exchanges over time and among different types and groups of exchanges. Specifically, the study inquires whether total factor productivity growth is primarily driven by improvements in efficiency or technological progress. Additionally, the paper focuses on the role of organizational status, structure, and cooperate governance influencing the performance of exchanges. A novum of this study is further that productivity analysis of European stock exchanges is performed in a non-parametric framework using DEA piece-wise linear production function and Malmquist productivity index. This approach permits to analyze simultaneously changes in total factor productivity and its components of pure technical change, scale efficiency, and technological change.

Clear evidence emerges from this study that European stock exchanges have exhibited positive productivity growth over the period. The results indicate a small overall rise in pure technical efficiency and a more significant overall technological progress. The empirical findings of this study support the view that technological innovation plays a pivotal role in shaping trading service provision during the 1993–1999 period. Technological progress can be interpreted as a sign of the dynamic nature of the whole exchange industry where stock exchanges take extra-ordinary efforts to adopt new cost-effective technologies and to cope with a changing security market environment. As a result, stock exchanges were able to take advantage of an intense diffusion of new technologies and information systems to leverage themselves on a higher production frontier. Automation of trading, electronic trading platforms, remote trading facilities and creation of networks among exchanges represent important characteristics of this sector for the period and for the near future. Additionally, the results report higher technological progress for exchanges that show characteristics of automation, equity and derivative trading, for-profit governance structure, large and mid-sized capitalized markets. This finding support the view that technological advances in stock exchanges has been an expensive exercise and that bigger and medium exchanges with larger capital backup and higher turnover of trades were more able to fund intense technological investments relative to their smaller counterparts.

The future of the European stock exchange industry comprises that technological innovation will continue to drive productivity. It is likely that creation of networked electronic trading platforms will provide potential for future productivity growth and improved efficiency in the provision of trading services. Additionally, it can be expected that merger activity in the form of strategic alliances or acquisitions could change productivity of the sector. Formation of mergers or alliances among exchanges in Europe is likely to have a beneficial effect on the overall productivity level as means to enhance efficiency or scale economies and to foster synergies, or even to increase market power by centralizing trading. Such alliances would enable co-operating exchanges to commonly invest in technological innovations or to rent out or sell new technologies to other trading service providers in order to achieve greater economies of scale. This would also lead to the use of more standardized technologies with a high degree of compatibility among different systems. The analysis of total factor productivity, pure technical efficiency, and technological change in this study provides valuable information to policy authorities and exchange decision-makers to pursuit future strategies that encourage technological innovation and foster productivity gains.

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