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Technology, automation, and productivity of stock exchanges: International evidence

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The views expressed are those of the authors and do not necessarily reflect the views of the Bank of Finland.

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Technology, automation, and productivity of stock exchanges: International evidence

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Abstract

The paper stresses on the importance of understanding the operational choices, strategies, and performances of stock exchanges as regular operating firms (Arnold et al (1999), and Pirrong (1999)) Using unbalanced panel data on 49 stock exchanges over the period 1989–1998, the paper traces the productivity of stock exchanges over time and across different types and groups of exchanges. We find significant variability in respect of the productivity – revenue and cost efficiency – across these exchanges. On average, North American exchanges are found to be most cost and revenue efficient. However, our findings also indicate that European exchanges have improved the most, in respect of cost efficiency, while exchanges in South America and Asia-Pacific regions are found to be lagging as regards both cost and revenue estimations. The evidence also indicates that investment in technology-related developments effectively influenced cost and revenue efficiency. Moreover, organisational structure and market competition are found to be significantly associated with both cost and revenue efficiency for the exchanges studied, whereas market size and quality are related only to revenue efficiency.

Key words: stock exchanges, technological progress, technical efficiency

JEL classification numbers: C23, G2, L2, O50

Tekniikka, automaatio ja osakepörssien tuottavuus: kansainvälisiä tuloksia

Suomen Pankin keskustelualoitteita 4/2002

Iftekhar Hasan – Markku Malkamäki – Heiko Schmiedel
Tutkimusosasto

Tiivistelmä

Tässä tutkimuksessa korostetaan, että pörssien toimintavaihtoehtoja, strategioita ja toimintaa tulee tarkastella samaan tapaan kuin muidenkin liikeyritysten. Vuodet 1989–1998 kattavan, 49:ää eri pörssiä kuvaavan aineiston avulla tarkastellaan tuottavuuden kehitystä erilaisissa pörsseissä. Osoittautuu, että pörssien tuottavuus, tuotto- ja kustannustehokkuus vaihtelevat varsin paljon. Pohjoisamerikkalaiset pörssit ovat keskimäärin tehokkaimpia sekä kustannusten että tuottojen osalta. Tulokset osoittavat kuitenkin myös, että Euroopassa pörssien kustannustehokkuus on parantunut nopeimmin samalla kun Aasian ja Tyynenmeren alueen sekä Etelä-Amerikan pörssit ovat kehittyneet muita hitaammin. Tulokset osoittavat myös, että pörssien investoinnit uuteen tekniikkaan ovat vaikuttaneet sekä tuotto- että kustannustehokkuuteen. Tämän lisäksi myös organisatoriset piirteet vaikuttavat otoksen pörsseissä sekä kustannus- että tuottotehokkuuteen, mutta markkinan koko ja laatu vaikuttavat vain pörssin tuottotehokkuuteen.

Asiasanat: osakepörssit, tekninen kehitys, tekninen tehokkuus

JEL-luokittelu: C23, G2, L2, O50

Contents

1 Introduction

Increased integration and consolidation of financial markets and institutions, changing technology and regulatory environment have altered the competitive norm within the stock exchanges industry. Consequently, exchanges are behaving more like regular firms adjusting to the new environment with increased automation, changing organisational governance, creating alliances and thus competing for increased market share, cost minimisation and revenue maximisation. These trends have been popular both in domestic markets as well as in the global arena (Arnold et al (1999), and Hasan and Malkamäki (2001)). The overwhelming consensus so far is that these changing initiatives and the growth of trading in exchanges are driven by the evolving technology which have caused reduction in communication and transaction costs and have encouraged exchanges to invade each others markets for order flows (Angel (1998), Lee (1998), and Wicker-Miurin and Hurt (1999)).

The exchanges therefore have been spending enormous resources in upgrading their technology and revising their business strategies to cope with the new environment.[1] Recently, for example NASDAQ has announced plans to establish new automated exchange SuperMontageSM designed to achieve best execution of trades;[2] New York Stock Exchange invested on another six Onyx2^{TM} visualisation supercomputers in its' already remodelled 3D visualisation operation centre (NYSE (1999)) believing that this investment will result into higher efficiency, effectiveness and the quality of operation. Such expectations are consistent with Brynjolfsson, Hitt, and Yang (2001) evidence of five dollars worth of market value for each dollar of installed new technology capital. The merging of exchanges has attracted market share and experienced narrower bid-ask spread (Arnold et al (1999)), lower cost and quality of trading (Bessembinder and Kaufman (1997)). Similar experiences are abundant in other countries and regions, primarily in Europe (Di Noia (2001), Schmiedel (2001)).

A number of interesting debates have emerged in the forefront of exchange analyses. One is whether and how beneficial are automation and new investments in "system development" by the stock exchanges? Second, whether the stock

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[1] Investment in information processing equipment accounted for about 34 per cent of total investment, surpassing the 22 per cent share of industrial machinery products invested in the economy (Triplett (1999)).

[2] SuperMontage^{SM} intends to bring together the auction and market maker system with a single point of entry for both quotes and order activity in contrast to the current Unisys 6830 quotation system, Automated Confirmation Transaction Service (ACT^{SM}) and Supersoes^{SM} technology. The SuperMontage^{SM} is going to be more costly but more affective than Supersoes^{SM} – introduced in the year 2000 – which uses Tandem's non-stop 50 Himalyn machines with each capable of handling 2000 transactions per second. For more details see www.nasdaq.com

exchanges are efficient as an operating firm? Does particular organisational structure influence exchange efficiency? Whether there exists significant economies of scale in the function of stock exchanges? And if so, would it result in dominance of a new large or few super regional exchanges eliminating the existence of the relatively smaller ones?

Domowitz and Steil (1999) report that advancement of automation has fundamentally changed the cost for trading services for the benefits of investors. Williamson (1999) calls technology as one of the key driving factors of structural changes and advancements of stock markets. Hasan and Malkamäki (2001) report significant existence of economies of scale and scope among stock exchanges. This is consistent with prior projections by Stigler (1961), Demsetz (1968) and Stulz (1999). On the other hand, some argue that any differences in price of risk across markets or existence of heterogeneous information will continue to delay any quick integration (Korajczyk (1997), Gehrig (1998a)). McInish and Wood (1996) further show that the impact of competition among markets produce tighter spread and lower liquidity premiums. In the popular business literature, there is also some consensus that the cost associated with the implementation of technology is somewhat of a sunk cost and the businesses are less likely to get back their resources spent on computer and related technology deemed in order to keep up with the current technology norms (Strassman (2001)).

Using an unbalanced panel data of 49 stock exchanges during the 1989–1998 period, this paper attempts to contribute further on these debates by tracing the productivity of stock exchanges over time and among different types and groups of exchanges. Importantly, it investigates among others the impact of technology on the revenue and cost efficiency of the sample exchanges. Additionally, it inquires the role of organisational type, structure, and corporate governance influencing efficiency. This is one of the very first comprehensive attempts in evaluating the performances of stock exchanges assuming that the exchanges are actually operative firms (Arnold et al (1999) and Pirrong (1999)). This approach is of great importance for the evolution of the market structures and contestability of the markets because stock exchanges make choices concerning, for example, their trading technologies ie the supply side of their trading services. Domowitz and Steil (1999) argue further that industrial structure of market places cannot be explained by focusing on the demand side alone as in financial market microstructure studies that concentrate on the characteristics of trading systems and the demand side of trading services ie the traders. It is equally important to know more about the provision of alternative technologies for trading services.

The overall results indicate that there exists some substantial revenue and cost inefficiency across exchanges. On average, North American exchanges are reported to be most cost efficient as well as revenue efficient. However, European exchanges are found to be the most improved exchanges in respect of cost efficiency. Exchanges in South America and Asia-Pacific regions are found to be substantially lagging in both cost and revenue estimations. Evidence indicates that investment in technology development effectively influenced cost effectiveness as well as revenue efficiency. Additionally, organizational designs and market competition are found to be significantly associated with both cost and revenue efficiency where as market size and quality are only associated with revenue efficiency.

The paper is organised as follows: Section 2 introduces stock exchanges and their activities, their operational mode, changes and recent developments in the industry followed by a brief literature review in section 3. Sections 4 to 7 introduce the data and measurement issues as well as the empirical models. Section 8 reports the results and the conclusions are given in section 9.

2 Stock exchanges and the changing environment

Stock exchanges are primarily in the business of security listing, trading, and clearing services, ie match making between buyers and sellers of securities, and providing a mechanism for discovering the price information. Exchanges are also involved in making revenue for the organisers of the market. In fact, unless the organisers are sufficiently compensated, they are less likely to provide funds and services needed to operate indefinitely (Angel (1998)). While the U.S. and Canadian exchanges have been operating in a competitive environment for a number of years, the European and Asian exchanges have historically been local monopolies. In Europe, it is only a recent phenomenon where exchanges are seen beyond being a public entity competing for customers and businesses with a corporate like "bottom-line" oriented organisations (Di Noia (2001)). Di Noia rightly points out that it is difficult to understand clearly what is the industry and what is the relevant market for exchanges? Fishel and Grossman (1984) assumed an exchange to be a large corporation that competes with other firms and is forced to produce the best price-quantity combination feasible. Ownership structure, however, makes the exchanges a bit different than firms as in some cases the customers are the owners of the firms as well. And it is likely that the owners of these exchanges may not be the best profit maximisers.

As Pirrong (1999) claims that the 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 the business. Networks will provide investors with options to choose among alternative preferences. The recent success of Eurex is a good example of how networks can replace a trading floor in another country. 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. These systems have gained increasing volumes, especially in stocks listed on NASDAQ as well as many NYSE-listed stocks.[3] This situation has opened possibilities of new scenarios in which economies of scales and expectation of further revenue and cost efficiency may lead to consolidation of traditional stock exchanges.[4]

Globally, a large number of new derivative and stock exchanges are established. In the 1990s alone, we have seen the emergence of 60 new exchanges.[5] Most of them are located in Asia-Pacific Rim and in Central and Eastern Europe. These new exchanges in emerging economies are functioning primarily in national markets and are local by nature and activities. While there is such increase in number of exchanges, a number of forces such as deregulation, technological developments and increased network externalities have created plausible environment for consolidation, especially in the European continent. The introduction of the euro has added further incentives to initiate alliances. Malkamäki and Topi (1999) believe that all these changes will allow financial institutions to take advantage of economies of scale in their operations, however, location will gradually lose some of its importance for market places and competition between financial centres, exchanges and settlement systems will intensify. New structures will emerge and even centres may become less important.

White (1996) emphasises the importance of uniform arrangements of regulations concluding substantial benefits associated with such harmonisation. The North American exchanges take a lead among all regions of the world in providing a relatively homogeneous regulatory framework for stock listings, trading, executions and settlements. Following the examples, the Europeans have taken recent initiatives to have uniform regulations in all areas. Barriers between European securities markets have been largely removed or overcome with the implementation of the OECD codes on free movement of capital by the end of 1980s and the Investment Services Directive by the mid-1990s. The predecessor of the ECB, European Monetary Institute (EMI), has published nine standards for the use of securities settlement systems in ESCB credit operations. These standards give guidance for the settlement systems in legal, custody, operational and risk management and disclosure issues. Standards also concern finality of settlement, operating times, regulation, and use of central bank money in

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[3] For more details on these issues, see Bessembinder and Kaufmann (1997), Domowitz and Steil (1999), Economides and Siow (1988), and Malkamäki and Topi (1999).

[4] At the same time, as new alternative electronic trading systems create new services and competition that may lead to fragmentation of liquidity and cream skimming.

[5] See Clayton et al (1999) and MSCI Handbook of World Stock, Derivative, and Commodity Exchange 1999.

settlement. The Asian and South American exchanges are under less centralised and harmonised regulatory umbrella and operate mostly under country specific unique rules and regulations.[6]

Developments in technology have been a major source of structural changes in securities markets during the last decades. It has created a foundation for modern electronic trading, clearing and settlement systems used in securities markets. Economic analysis suggests that a single market will come into being if there are no regulatory barriers that prevent the formation of a single market and advanced telecommunication technologies exist ie if the market is not dependent on physical location. Hasan and Malkamäki (2001) indeed find that economies of scale are clearly present in stock exchange trading systems. The authors argue that the rapid advance in communications technology has served to minimise the fragmenting effect of physical distance on exchange formation. 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. 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, 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. He 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 exchanges other than the NYSE are actually cream skimming as some of them concentrate on trades that take advantage of price discovery in the NYSE. It is also seen that realised bid-ask spreads are higher for shares that are subject to cream skimming. Thus the validity of the NYSE market price 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

[6] See Freedman (1999), Malkamäki and Topi (1999) and White (1996) for more details.

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.

The theoretical and empirical analysis both suggest that economies of scale and cost efficiency is a major source of competitive pressure in stock exchange environment if the necessary preconditions for the contestable markets are fulfilled. Moreover, new technology facilitates additional ways how the infrastructure may develop. Especially, trading platforms of stock exchanges meet increasing competition from less organised marketplaces. In the U.S. markets, the appearance of off-exchange trading institutions, like Arizona Exchange, Instinet and Posit, using Internet as an essential transmission channel has already created a noteworthy challenge to existing stock exchanges and traditional brokers. The value of the Internet lies in its capacity to provide immediate access to information at very modest costs.

Although euro security markets together became the second largest in the world after the U.S. markets, however, the size of the market for euro denominated securities is much lower – relative to the size of the economy – than the size of the securities markets in the United States. The securitisation is likely to proceed in Europe because of the increased size and liquidity of the euro securities markets compared with the former individual national securities markets (McCauley and White (1997), Prati and Schinasi (1997), and Duisenberg (1999)). The introduction of the euro and other measures contributing to the European integration are lifting the European securities and derivatives markets to the global picture. Demand for cross-border financial services has increased rapidly. Asset managers and brokers have to be able to operate on many markets. This has led the biggest banks and securities houses to look for scale advantages by acquisitions and mergers. Within Europe, competition among marketplaces and institutions operating trading and settlement systems is rapidly intensifying. Several intercontinental mergers of listed companies also raise a question where trading of these companies' shares will take place in the future. Global competition about the liquidity is obviously about to begin.

In respect of the organisational structure, the automated trading system creates a new environment as this type of structure allows to specialise more in producing trading services and have appeared to capture market share quite easily especially in the U.S. market. Many exchanges, formerly co-operatives changed their ownership structure to a profit motivated corporation. Some exchanges eg NYSE, have both traditional trading floor based auction market as well as electronic books and automated network.

The success of Eurex relative to LIFFE may, on the other hand, be partly explained by differences in the governance of these two exchanges. 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 is not in their own interest in the longer run.

3 Related literature

A number of studies focused on scale economies in information processing and the future of financial centres. Stigler (1961) published one of the first studies on the scale economies in securities markets followed by a more extensive paper by Doede (1967). These papers report that average operating costs of stock exchanges are a declining function of trading volume and there seem to have evidence of economies of scale in the industry. Demsetz (1968) focuses on the bid-ask spreads finding them to be a declining function of the rate of transaction volume thus claiming some sort of economies of scale in the market making of a particular security. Smith (1991) highlights the declining marginal cost of information and the benefits of integrated markets. Domowitz (1995) argues that common electronic trading platforms, ie, implicit mergers between existing exchanges will emerge because of the positive liquidity effect and such implicit mergers will allow increased revenue as individual exchanges are likely to set prices above marginal cost. Cybo-Ottone et al (2000) investigates the European exchanges during the 1993–1994 period reporting potential differences in level of efficiency and performance across exchanges based on cost to revenue ratios. Hasan and Malkamäki (2001) find that overall economies of scale exist among the big exchanges especially in the North American and European exchanges alluding to increased productivity in the future.

Davis (1990) reports that innovation in technology and new uniformity of regulation in the EU countries would lower entry barriers, foster competition and performance. Gaspar and Glaeser (1996) shows that telecommunications is a complement rather than a supplement for financial centres and thus contradicted prevalent argument that telecommunications will eliminate the significance of traditional exchanges and locations. Grilli (1989), Krugman (1991), and Gehrig (1998b) claim that technological condition, economies of scope and scale are the sources of potential agglomeration and performance among markets. Brennan and Cao (1997) and Grinblatt and Keloharju (2001) present the importance of culture, language and related behavioural aspects of investors and institutions over distance, technology and related issues in determining performance.

A number of studies either compare or discuss theoretical predictions of the differences in performances with respect to the exchanges in the U.S. markets based on some form of regulation, market or organisational differences. Bhattacharrya and Spiegel (1991) focus on the differences in enforcement of trading laws while Biais (1993) discuss market differences between a centralised single venue and fragmented marketplace. Huang and Stoll (1996) discuss the differences between NYSE and the NASDAQ markets finding a higher spread on the NASDAQ, the dealers market. Domowitz and Steil (1999) look into the differences between trading floor and automated electronic order-based trading and also between mutual and non-mutual institutions.

A few of the related papers focus on multi-country environment. Perold and Sirri (1997) investigate cross-country variation of cost of trading followed by a similar paper by Domowitz et al (1999) that focus on the simultaneous relationship between cost, liquidity, and volatility. 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 the 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.

Except for Domowitz and Steil (1999) and Hasan and Malkamäki (2001) most other studies discussed above focus primarily on the demand side that deal with the characteristics of trading systems, trading services, and exchanges' ability to attract liquidity, its spread and volatility. Following the basic arguments of Arnold et al (1999) and Pirrong (1999), this paper evaluates the performances of stock exchanges where exchanges are considered as operative firms and thus stresses on the importance and provisions of the supply side of their trading services.

Moreover, this paper deals with a multiyear, global data set that avoids any regional bias. Given the differences in the extent of initiatives of consolidations, implicit alliances, and co-operation among exchanges in different regions (especially in Europe), it is important that a study provides separate perspectives for different regions. Therefore, we use the information of a panel of 49 exchanges during the sample years in 4 continents to investigate our research questions.

4 Measurement issues

In general, it is controversial what constitutes inputs or outputs for any financial institutions. It is even more difficult to do so for the exchanges as mentioned earlier, it is not obvious even what is the stock industry and what is their relevant market? In general, the processing of fairly homogeneous transactions and evaluations of issuer-specific information can be seen as two separate functions. A close look at the operations and annual reports of stock exchanges would confirm such notions of two functions producing two outputs (Hasan and Malkamäki (2001)). Stock exchanges have computers, software and personnel for matching and processing trades. They also have the personnel and regulations needed to maintain the marketplace and to communicate with companies in order to handle the listing of companies and to monitor how company-specific information is released and whether companies observe the regulations set by the marketplace. The literature suggests that such activities, based on very simple information, tend to be centralised. Limit orders and market orders can actually be considered standardised information, and the processing of this information is technical and not issuer-specific, ie all the transactions are treated in more or less the same way in the trading system. Thus execution of trades can realistically be based on technology that is standardised throughout each country or region. On the other hand, more complex, issuer-specific information may require face-to-face contacts for proper understanding. Centralisation in this area may cause congestion problems and may be costly. It might therefore be optimal that listing procedures and communication with companies and other related matters be handled by the national exchanges.

Following some of the justifications and arguments above, we consider relevant proxies for output of the trading system that seems to be fairly obvious and we can get consistent data such as the number and value of executed transactions. The output relating to the listing procedure of companies and monitoring of company-specific information is more difficult to measure. Possible proxies for this output might be number and value of listed companies. There are no direct measures available for inputs of stock exchanges. The two most important input prices for the operations of stock exchanges (see Table 1), are trading system (technology and office expenses) and employee costs. Based on the averages of the available sample period, in respect to office expenses, Asian exchanges had significantly higher proportion of expenses. For labour cost, a significantly higher proportion of expenses by exchanges in the North America (38.40%) relative to other regions eg Asia-Pacific region (28.90%), European exchanges (32.52%), and South American exchanges (18.0%).

Disaggregated labour data is unavailable for many of the annual reports. We started our empirical research by including at least one relevant input price variable, GDP (Gross Domestic Product) per capita as a proxy for differences of labour costs across countries. Later we concentrate on sub-sample regressions for which we have clean data for labour expenses. In fact, we were able to get the actual labour cost data for 26 of the exchanges. Interestingly, the estimations using per capita GDP as labour input proxy did not yield significantly different results for the 26 exchanges compared to estimations that actually use the direct measure of labour price as an input.

Table 1. **Distribution of average cost structure by region (percentages of total cost)**

	Systems	Administration	Staff	Office	Depreciation	Other
Asia	18.8	16.0	28.9	11.5	9.5	15.2
	(16.2–23.1)	(14.2–18.7)	(27.7–30.0)	(10.1–12.3)	(9.3–9.9)	(11.0–19.0)
Europe	21.93	7.60	32.32	8.22	10.93	18.97
	(18.9–26.6)	(6.6–9.0)	(28.5–35.1)	(7.8–8.9)	(9.9–12.2)	(18.2–20.0)
North America	20.7	10.6	38.4	4.5	8.7	17.3
	(17.3–23.2)	(7.3–13.9)	(33.9–43.4)	(4.3–4.7)	(8.3–9.1)	(12.3–23.2)
South America	8.9	21.7	18.0	5.3	10.0	34.5
	(8.5–9.4)	(19.6–23.0)	(13.6–20.6)	(5.7–7.9)	(10.4–12.1)	(27.9–39.6)

Notes: Averages are based on the last three years of information provided by the FIBV. The distribution range is given in brackets. Data previous to these years do not provide segmented information.

Some of the stock exchanges have expanded their operations to include derivatives and settlement business. Many of these stock exchanges do not publish sectoral cost figures. In order to incorporate such differences in reported cost data, we add a dummy variable in all regression estimations highlighting those exchanges whose business activities and cost data include derivatives and/or securities settlement expenses, in addition to the output and input variables.

The following are the models we have attempted to estimate with the intention of investigating our research questions with the possibility of including highest numbers of sample exchanges in the data set. Model 1 includes 2 outputs (number of companies, value of shares traded) and 1 input (GDP per capita) during the 1989–1998 sample years. Model 2 is the same as model 1 except the sample period considered is 1993–1998. Model 3 keeps the same outputs, however, uses more direct measures of inputs, which are price of labor and price of capital. It also adds a netput variable, transaction velocity, to control for the quality aspect of the exchange operation. Additionally, the model includes environmental variable, industrial production during the sample year. Model 4 is similar to model 3, additionally it includes technological change that associates time trend with output, input, and netput variables.

5 Empirical methodology

In carrying out our empirical analysis, we use the methodology developed by Aigner, Lovell, and Schmidt (1977), Meeusen and Broeck (1977) and Stevenson (1980) – stochastic frontier approach – to calculate a measure of production efficiency, revenue and cost inefficiency scores, for each of the sample stock exchanges.[7] The stochastic frontier function to be estimated, eg a maximum revenue or a minimum cost frontier, incorporates a two-component error structure – one being a controllable factor and the other a random uncontrollable component. For an i-th producer in the t-th time period, we observe,

$$TC_{it}(TR_{it}) = f(Y_{it}, P_{it}, Z_{it}, T) + SR_{it} + D_{it} + \varepsilon_{it} \tag{5.1}$$

with $i = 1,...,N$ and $t = 1,...,S$, where TC_{it} (TR_{it}) represents the firm's total cost (total revenue), the Y_{it} represents the various products or services produced by the firm, P_{it} represents the prices of the inputs used by the firm in the production of the products and services, Z_{it} represents the fixed netput quantities, quality of output, T represents technology change, SR_{it} represents environmental variable, D_{it} is a dummy for exchanges with both derivatives and security settlements and ε_{it} represents a random disturbance term which allows the cost function to vary stochastically, that is, it captures the fact that there is uncertainty regarding the level of total costs or revenue that will be incurred for given levels of production. Decomposing the error term yields,

$$TC_{it}(TR_{it}) = f(Y_{it}, P_{it}, Z_{it}, T) + SR_{it} + D_{it} + u_{it} + v_{it}(-u_{it} + v_{it}) \tag{5.2}$$

with $i = 1,...,N$ and $t = 1,...,S$, where v_{it}'s represent random uncontrollable factors that affect total costs, such as weather, luck, labour strikes, or machine performance. The v_{it}'s are identically distributed as normal variates and the value of the error term in the cost and revenue relationship is, on average, equal to zero. The u_{it}'s, on the other hand, represent the controllable components – consisting of factors such as technical and allocative efficiency of the firm that are under the control of firm's management. The u_{it}'s are derived from a $N(0, \sigma_u^2)$ distribution truncated below zero. Following Jondrow, Lovell, Materov, and Schmidt (1982), insight into controllable firm efficiency can be gained by considering the ratio of variability of the firm's technical and allocative efficiency. The frontier function approach maintains that managerial or controllable inefficiencies only increase (decrease) costs (revenue) above (below) frontier or best practice levels and that random fluctuations can either increase or decrease costs (revenue). Since uncontrollable factors are assumed to be symmetrically distributed, the frontier of the cost (revenue) frontier, $f(.) + \varepsilon_{it}$, is clearly stochastic. The positive (negative in a revenue function) term, u_{it}, representing inefficiency, causes the cost (revenue) of each firm to be above (below) the frontier.

Jondrow et al (1982) demonstrate that the ratio of variability ($\lambda = \sigma_u/\sigma_v$) for u_{it} and v_{it} can be used to estimate a firm's relative inefficiency. Small values of λ

[7] See Kumbhakar and Lovell (2000) for extensive details on the literature.

imply that the uncontrollable factors σ_v dominate the controllable inefficiencies σ_u. A measure of controllable inefficiency for the i–th firm is formulated as:

$$E[u|\varepsilon] = \sigma\lambda/(1+\lambda^2)[\phi(\varepsilon\,\lambda/\sigma)/\Phi(\varepsilon\lambda/\sigma) + \varepsilon\,\lambda/\sigma] \tag{5.3}$$

where $\sigma = (\sigma_u^2 + \sigma_v^2)^{1/2}$, ϕ is the standard normal density function, Φ the cumulative normal density function, and all other terms are as previously defined.

A commonly used translog functional form is employed here to estimate the cost und revenue performance measures of the stock exchanges. The general form of the translog function is defined as follows:

$$\begin{aligned}\ln TC_{it}\ (\ln TR_{it}) = {} & \alpha_0 + \sum_{k=1}^{2}\alpha_k \ln Y_{kit} + \sum_{l=1}^{2}\beta_l \ln P_{lit} \\ & + \frac{1}{2}\sum_{k=1}^{2}\sum_{m=1}^{2} x_{km} \ln Y_{kit} \ln Y_{mit} + \frac{1}{2}\sum_{l=1}^{2}\sum_{n=1}^{2}\gamma_{ln} \ln P_{lit} \ln P_{nit} \\ & + \sum_{k=1}^{2}\sum_{l=1}^{2}\delta_{kl} \ln Y_{kit} \ln P_{lit} + \phi_1 \ln Z_{it} + \frac{1}{2}\phi_2 \ln Z_{it} \ln Z_{it} \\ & + \sum_{k=1}^{2}\lambda_k \ln Y_{kit} \ln Z_{it} + \sum_{l=1}\theta_l \ln P_{lit} \ln Z_{it} + \omega_1 T + \frac{1}{2}\omega_2 TT \\ & + \sum_{k=1}^{2}\tau_k \ln Y_{kit} T + \sum_{l=1}^{2}\kappa_l \ln P_{kit} T + M \ln Z_{it} T \\ & + R_t \ln I_{Prod} + D_1 + \varepsilon_{it}\end{aligned} \tag{5.4}$$

where, $x_{km} = x_{mk}$ and $\gamma_{ln} = \gamma_{nl}$ by symmetry, $\sum_l \beta_l = 1$, $\sum_{ln}\gamma_{ln} = 0$, $\forall i$, $\sum_l \delta_{kl} = 0$, $\forall i$, $\sum_l \theta_l = 0$, and $\sum_l \kappa_l = 0$ by linear homogeneity. Efficiency scores are calculated by converting individual stock exchange inefficiency score u_i to relative efficiency using the definition:[8]

$$EFF_i = \exp(\min[\ln u_t)] - \ln u_{it}) = \frac{\min[u_t]}{u_{it}} \tag{5.5}$$

[8] For more details see DeYoung (1997).

6 Correlates of cost and revenue efficiency

Once we have attained the revenue and cost efficiency scores, we employ a series of estimates to investigate possible correlation between such inefficiency and other relevant organisation-specific and other related variables reflecting among others, firm strategy, portfolio positions and management practices. Among other issues, we are interested in seeing whether the influence of technology related initiatives and expenses are significantly correlated with the revenue and cost efficiency scores. We are also focused on the correlation between efficiency scores and organisational set-ups of the exchange, eg, automated versus hybrid, exchanges with derivative trading facilities versus equity only trading exchanges. Simple correlation as an alternative to regression analysis attempts to make a point that causation may run in both directions (Mester (1996)).

Mester rightly points out some of the limitations of a two-step procedure. While such analyses are suggestive but not necessarily conclusive as the dependent variable 'inefficiency' in the regressions is an estimate and the standard error of this estimate is not accounted for in the subsequent regression or correlation analysis. One should interpret the results as providing information on correlation only instead of causality as the variables used in the estimation also suffer from endogeneity problem and thus bias the coefficient estimates. We estimate both multiple- and single variable regressions. Including an endogenous variable in a multiple regression can bias the coefficients even on exogenous variables. Berger and Mester (1997) cautions that perhaps all of our variables are partly endogenous and partly exogenous. In single variable estimate, the drawback is that the correlation traced may be spurious, with both efficiency score and the independent variable being strongly related to another omitted variable. Given the pros and cons of both methods, any conclusive statements should be taken with caution except when particular variable behave in a similar fashion in both estimates and are highly statistically significant.

Using the individual efficiency scores, the second-step regression includes the following variables:

$$
\begin{aligned}
COSTEFF_{it}\ (REVEFF_{it}) = a_0 &+ b_1 TECHCOST_{it} + b_2 EQTDERIV_{it} \\
&+ b_3 AUTOM_{it} + b_4 3FIRM_{it} \\
&+ b_5 NOEXCH_{it} + b_6 PROFIT_{it} \\
&+ b_7 RMERGER_{it} + b_8 THOURS_{it} \\
&+ b_9 TURNOVER_{it} + b_{10} INDEX_{it} \\
&+ (b_{11} LISTFEE_{it} + b_{12} TRADEFEE_{it} \\
&+ b_{13} COSTEFF_{it}) + \varepsilon_{it}
\end{aligned}
\tag{6.1}
$$

COSTEFF or REVEFF represents cost efficiency or revenue efficiency scores derived in the previous section. All independent variables are measures of some sort of proxy for management practice, organisational designs, business experience and performance, as well as market competition.

TECHCOST includes all technology and automation related cost undertaken by the exchanges during the sample year as a ratio of total cost of the exchange. As the debate on this issue says that it is plausible that higher investment in technology may correspondent to higher efficiency where as it is also can be the likely cause of lower performance. Therefore, the expected magnitude of the variable can be in two possible directions. EQTDERIV is a bivariate variable, which takes a value of 1 if the stock exchange is involved in both equity and derivative trading and takes a value of 0 for all other exchanges. This dual activity of the exchange may lead to higher cost at least in the early years causing a negative relationship with cost and revenue performance. AUTOM is a bivariate variable. A value of one stands for fully automated exchanges or exchanges that maintain a primarily automated trading environment. It takes a value of zero for exchanges that are either an auction market or markets with primary importance of the auction market, eg NYSE. The market share of the top three firms in a given exchange is captured by 3FIRM. It is likely that markets with relatively higher monopoly of few firms may affect the efficiency negatively. NOEXCH represents the number of the exchanges in respective countries where the sample exchange is located. It is also a measure of market competition faced by the exchange. It is likely that the higher the number of competitive exchanges the higher (lower) are the cost (revenues) of the individual exchange respectively. This higher cost could be a number of areas including higher human capital and marketing cost. Such scenario is more likely to cause lower efficiency. However, it can also be argued that competition creates an environment where businesses tend to eliminate some expenses otherwise deemed routine. PROFIT is a bivariate variable takes a value of one for exchanges that are profit oriented either being traded in the market or being a company with normal corporate structure. Otherwise, it takes a value of zero where the exchanges are primarily non-profit motivated and mutual institutions. It is more likely that stock institutions or profit-oriented exchanges will have higher incentive to be efficient due to increased pressure and monitoring. RMERGER represents a bivariate variable that takes a value of one for exchanges that have explicitly or implicitly merged with another exchange(s) within the past three years. THOURS is the number of hours the exchange is open for trading. Being open for longer hours could be a costly matter for the exchanges but on the other hand the additional hours of trading may bring additional revenue. TURNOVER represents the velocity of the exchange measured as a ratio of value of equity traded to market capitalisation. Markets with higher turnover are likely to be more efficient. INDEX, is the market size represented by the natural logarithm of the respective market indexes. We have also included, although not reported here, a series of bivariate variables controlling for the sample years. In the revenue efficiency regressions, we include listing and trading fees and cost efficiency as additional independent variables in determining revenue efficiency scores.

7 Data and descriptive statistics

The data used in this study come from a variety of sources, including annual reports of stock 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 data were collected from annual balance sheets, income statement reports, and Internet pages of all major operating stock and derivative exchanges covering a 10-year time period (Annual Reports 1989–1998). 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 information on exchange-specific characteristics. Although reporting schemes and information content of the financial accounts vary across time and exchange, however, a consistent data set has been constructed including all necessary information on 49 individual exchanges key balance sheet and income statement items, of which observations of 44 exchanges over the period from 1989–1998 finally entered the estimations. All national currencies are converted into U.S. $ and are inflation adjusted using data from IFS. All variables other than qualitative proxies are expressed in natural logarithms.[9]

Table 2 provides average cost and average revenue perspectives of these sample exchanges based on their exchange locations in respective geographical continents. We see major differences across average cost and revenue variables with out any overwhelming trend of such differences. South American exchanges have some of the highest average total costs as well as average revenue per trade among the sample institutions. Although the cost per trade reported for North American exchanges are higher than the European and Asia-Pacific groups, however, once adjusted for the value of shares traded, the cost unit dropped to the lowest among the groups. Except for trading fee and the share size of the markets in North America, overall, exchanges in North America and Europe have similar cost and revenue structures relative to Asia-Pacific and South American groups'

[9] See Hasan and Malkamaki (2001) for more details on the sample exchanges.

statistics in most cases.[10] Table 3 provides the descriptive statistics for some of the bivariate and related variables used in the estimation.

Table 2. **Distribution of cost and revenue structure of stock exchanges**

		Regions			
Variables or ratios	**Combined**	**Asia-Pacific**	**Europe**	**North America**	**South America**
Average Total Cost (ATC) in 000's	81.645	64.848 (2.964–356.148)	62.166 (1.524–452.758)	168.474 (17.612–564.666)	49.890 (6.832–83.276)
ATC to Number of Trade	16.67	14.46 (0.9–63.8)	11.5 (2.1–26.5)	17.15 (3.8–36.6)	36.84 (9.9–62.5)
ATC to Value of Share traded	1.05	1.08 (0.15–7.4)	1.24 (0.2–8.3)	0.92 (0.13–3.9)	1.39 (0.32–4.1)
Employee Cost to ATC	32.13	29.48 (24.4–35.1)	34.83 (30.16–38.2)	37.14 (35.8–41.0)	21.95 (13.2–27.6)
Office Cost to ATC	8.91	12.69 (8.4–13.1)	9.38 (1.5–10.1)	6.32 (4.0–9.6)	6.90 (6.2–7.3)
Technology Cost to ATC	11.89	3.95 (0.30–9.5)	14.65 (1.01–26.8)	16.23 (8.2–22.8)	4.93 (4.2–5.5)
Average Total Revenue (ATR) in 000's	99.587	78.996 (7.970–372.477)	78.857 (1.651–561.327)	193.921 (19.110–634.380)	72.451 (8.079–91.762)
ATR to Number of Trade	21.76	15.09 (1.10–10.5)	22.63 (4.8–29.8)	19.04 (4.12–44.27)	48.63 (10.2–76.5)
ATR to Value of Share Traded	2.28	2.01 (0.3–10.5)	3.25 (1.03–12.56)	1.82 (0.21–6.8)	1.66 (0.36–3.9)
Listing Fee Income to ATR	18.97	14.45 (1.9–16.8)	18.06 (1.8–34.3)	21.49 (8.0–32.2)	6.71 (2.4–10.1)
Trading Fee to ATR	38.66	43.97 (10.41–70.31)	51.92 (40.1–70.2)	40.31 (34.6–46.3)	36.97 (19.6–49.4)

Notes: (1) Distribution Range is given in the (parenthesis); (2) All currencies are converted to dollar and inflation adjusted.

[10] All the different ratios reported in table 2 are not based on the same number of sample exchanges as eg the information on technology cost, listing and trading fees are limited to 26 exchanges to a combined total of 84 during the sample years.

Table 3. **Descriptive statistics (1989–1998)***

Panel A

Regions	Number of Sample Exchanges	Number of Companies Traded	Average Number of Exchanges in the Country	Equity Transactions (000000)
Combined	49	776	4.12	12.122
Asia-Pacific	14	642	4.54	16.163
Europe	22	618	2.49	5.790
North America	8	1425	7.33	23.011
South America	5	470	5.70	1.607

Panel B

Regions	Value of Equity shares (000)	Market Index	Market Return	Market Value to GDP (%)	Top 3 Company Market Share
Combined	376.569	9984	23.18	87.6	22.7
Asia-Pacific	200.395	2489	9.30	62.1	18.5
Europe	277.704	17222	33.76	78.3	27.3
North America	1.061.615	2787	17.05	128.5	12.8
South America	95.578	15.572	34.75	41.4	36.85

Panel C

Regions	Merger Dummy	Equity Only Dummy	Fully Automated (no auction)	Profit Motivated Ownership Dummy	Turnover Ratio
Combined	0.41	0.71	0.74	0.11	63.61
Asia-Pacific	0.32	0.40	0.89	0.06	66.89
Europe	0.47	0.69	0.82	0.19	63.87
North America	0.52	0.88	0.55	0.0	55.62
South America	0.0	1.0	0.22	0.0	61.27

8 Empirical evidence

The translog cost and revenue function estimates for each of the four model specifications are reported in table 4 and 5. All parameters associated with these estimates are reasonably consistent with the expectations. In most cases, the output and input specifications and binary variable turned out to be statistically significant. But importantly for such models, the R-squared and F-statistics exonerating the choice of output and input variables considered in this study.

These models result the above discussed measures of relative cost efficiency and relative revenue efficiency for each of the sample exchanges. As mentioned earlier, we estimate several cost and revenue models using alternative input and other specifications. The efficiency scores should be considered as the average efficiency of a given stock exchange relative to the best practice stock exchange in the sample. The tables 6 and 7 report the weighted averages of relative cost and revenue estimations for each of the models. In table 6, the combined estimates show that cost efficiency of the exchanges ranges from 85.04% to 92.69%. In other words, about 7% to 15% of incurred cost can be attributed to lost efficiency relative to "best cost practice" stock exchange depending on the model specification used in the estimation. In table 7, we find that the combined average scroes range from 79.03% to 89.44% meaning an at least 10% of potential revenue loss relative to the "best revenue practice" exchange. Tracing yearly averages in both tables, we see that in all estimates, there is an increase in cost and revenue efficiency scores over the sample period as indicated by the averages reported for 1989, 1993, and 1998.

Focusing further on the results reported by model 4 of cost estimates (table 6), a more appropriate model that adjusts for quality control, economic environment, and technological change over the time period 1993 to 1998, we see that the range of efficiency spreads from a low 75.39% among South American exchanges to a high 89.64% among North American exchanges. It also shows that the efficiency average improves from an average of 80.16% in 1993 to an average of 91.76% in 1998. The same model 4, in the revenue estimates (table 7), shows lower revenue efficiency estimates by the South American exchanges (72.60%) and high efficiency scores (85.29%) reported by the North American exchanges. Average revenue scores also improved slightly from 79.11% in 1993 to 84.04% in 1998.

We further analyse the estimates of model 4 by providing weighted average scores by each of the sample years according to their geographical locations as well as to their different organizational designs, types, and sizes. These estimates are reported in table 8 and 9 for cost and revenue efficiency respectively. The combined estimates in both tables are consistent with previous results where there is evidence of continuous cost and revenue efficiency improvements over the sample period. The estimates in both tables also show significantly lower scores for South American and Asia-Pacific exchanges. In the cost estimations, the South American exchanges show substantial improvement in cost efficiency over the sample years.

Table 4. **Cost regression parameters**

Variable Coefficient	Model 1 (1989–1998)	Model 2 (1993–1998)	Model 3 (1993–1998)	Model 4 (1993–1998)
α_0	–9.6128	–2.0564 *	–1.0823	2.7550
	(1.01)	(1.90)	(0.57)	(1.26)
α_{Y1}	3.5009 ***	2.8931 ***	1.5836 ***	1.0932 ***
	(20.65)	(30.29)	(32.57)	(24.45)
α_{Y2}	–0.4170	–0.3201	–0.4284 **	–0.3079 *
	(1.43)	(1.57)	(2.00)	(1.70)
x_{Y1Y1}	–0.0007	–0.0060	0.0474 **	0.0409 **
	(0.02)	(0.20)	(2.17)	(2.04)
x_{Y2Y2}	0.1722	0.1430	0.0450	0.0561
	(1.25)	(1.35)	(0.43)	(0.29)
x_{Y1Y2}	–0.1034 **	–0.1056 **	–0.1670 ***	–0.1445 ***
	(2.10)	(2.58)	(3.61)	(3.54)
β_{P1}	1.6955 *	1.4219 **	0.6645 **	0.6244 **
	(1.83)	(2.13)	(2.16)	(2.32)
$\gamma_{Y1.P1}$	0.0076	0.0070	0.0361	0.0367
	(0.56)	(0.66)	(0.35)	(0.31)
$\delta_{Y1.P1}$	–0.3805 **	–0.3035 **	–0.3287 ***	–0.3100 ***
	(2.41)	(2.57)	(3.01)	(4.21)
$\delta_{Y2.P2}$	0.1009	0.1216	0.1835 **	0.1807 **
	(0.32)	(0.53)	(2.18)	(2.26)
ϕ_Z			–0.5634 *	–0.4875 **
			(1.88)	(2.05)
ϕ_{ZZ}			0.0345 **	0.0340 **
			(2.55)	(2.68)
$\lambda_{Y1.Z}$			–0.3246 ***	–0.2803 ***
			(3.48)	(3.08)
$x_{Y2.Z}$			0.1090 ***	0.1188 ***
			(3.14)	(3.98)
$\theta_{P1.Z}$			0.4507 **	0.4034 *
			(2.16)	(1.85)
$R(I_{PROD})$			–0.0760 **	–0.0733 **
			(1.99)	(2.37)
$\omega_1 T$				–0.7705 ***
				(3.71)
$\omega_2 TT$				0.0085
				(1.57)
$\tau_{Y1.T}$				–0.0663 **
				(2.30)
$\tau_{Y2.T}$				0.0001 ***
				(7.00)
$\kappa_{P1.T}$				0.0654
				(1.45)
$M_{Z.T}$				–0.0366 **
				(2.74)

Variable Coefficient	Model 1 (1989–1998)		Model 2 (1993–1998)		Model 3 (1993–1998)		Model 4 (1993–1998)	
Derivative	–1.8175	***	–1.4545	***	–0.8721	***	–0.6542	***
Dummy	(10.60)		(10.04)		(198.00)		(145.64)	
Log-likelihood	–469.944		–400.3090		–582.061		–564.053	
λ	2.6403	**	2.0945	**	3.8704	**	3.0046	**
	(2.08)		(2.02)		(2.57)		(2.39)	
σ	9.5435	***	8.4576	***	5.5681	**	5.0074	**
	(3.04)		(2.80)		(2.27)		(2.36)	
N	176		102		102		102	

Note: ***, **, * mean significant at 1%, 5% and 10% levels respectively. I_{PROD} = Industrial production. Model 1 uses per capita GDP as inputs whereas models 2, 3 and 4 use actual labour and capital expenditure as inputs. T-values are reported in brackets.

Table 5. **Revenue regression parameters**

Variable Coefficient	**Model 1 (1989–1998)**	**Model 2 (1993–1998)**	**Model 3 (1993–1998)**	**Model 4 (1993–1998)**
α_0	227.5800	188.0600	964.5500 *	188.0500
	(0.29)	(0.30)	(1.91)	(0.18)
α_{Y1}	1.0967	0.9822	1.1408 ***	1.0441 ***
	(0.26)	(0.42)	(28.84)	(29.83)
α_{Y2}	0.9077	0.8931	0.3500 *	0.3832 **
	(0.05)	(0.01)	(1.86)	(2.32)
x_{Y1Y1}	–0.2688	–0.2568	–0.0380 *	–0.0405 *
	(0.11)	(0.13)	(1.82)	(1.73)
x_{Y2Y2}	1.0166	0.8952	0.0404	0.0302
	(0.12)	(0.14)	(0.14)	(0.40)
x_{Y1Y2}	–0.1267 **	–0.1186 **	0.1821 **	0.1088 **
	(2.10)	(2.08)	(2.60)	(2.73)
β_{P1}	–3.5546	–3.0619	–0.6645 **	–0.5695 **
	(0.06)	(0.05)	(2.16)	(2.53)
γ_{P1P1}	0.0770	0.0743	0.0289	–0.0120
	(0.08)	(0.13)	(0.38)	(0.16)
$\delta_{Y1.P1}$	0.5406	0.4433	0.1850 **	0.2540 *
	(0.07)	(0.07)	(2.19)	(1.83)
$\delta_{Y2.P2}$	–0.2406	–0.1853	0.2134 **	0.1520 **
	(0.02)	(0.02)	(2.00)	(2.07)
ϕ_Z			0.5634 *	0.6158 **
			(1.88)	(2.08)
$\phi_{Z.Z}$			0.0567 ***	0.0467 ***
			(3.00)	(4.51)
$\lambda_{Y1.Z}$			–0.2885 **	–0.2855 **
			(2.23)	(2.03)
$x_{Y2.Z}$			0.0856 **	0.1304 **
			(2.86)	(2.86)
$\theta_{P1.Z}$			0.3844	0.3562
			(1.50)	(1.34)
$R(I_{PROD})$			0.0907 *	0.0567 *
			(1.83)	(1.91)
$\omega_1 T$				0.0356 **
				(2.78)
$\omega_2 TT$				–0.0304
				(1.31)
$\tau_{Y1.T}$				0.0592
				(2.22)
$\tau_{Y2.T}$				0.2955
				(1.26)
$\kappa_{P1.T}$				–0.0248
				(0.13)
$M_{Z.T}$				0.3420 **
				(2.52)

Variable Coefficient	**Model 1 (1989–1998)**		**Model 2 (1993–1998)**		**Model 3 (1993–1998)**		**Model 4 (1993–1998)**	
Derivative	0.0660		0.0601		0.6604	***	−0.6670	***
Dummy	(0.18)		(0.14)		(14.51)		(14.62)	
Log-likelihood	−0.5328		−1.2904		−7.0493		−4.3201	
λ	1.8488		2.0732		6.2455	**	3.0544	**
	(0.14)		(0.18)		(2.35)		(2.42)	
σ	265.0800	**	275.0500	**	5.0833	**	4.8842	**
	(2.44)		(2.60)		(2.43)		(2.37)	
N	176		102		102		102	

Note: ***, **, * mean significant at 1%, 5% and 10% levels respectively. I_{PROD} = Industrial production. Model 1 uses per capita GDP as inputs whereas models 2, 3 and 4 use actual labour and capital expenditure as inputs. T-values are reported in brackets.

Table 6. **Relative cost efficiency**

	Model 1	Model 2	Model 3	Model 4
Combined Sample	89.21	86.54	92.69	85.04
	(74.2–98.6)	(73.1–96.4)	(74.1–98.6)	(68.4–98.6)
Asia-Pacific	86.08	84.29	90.39	80.62
	(81.73–96.7)	(80.2–95.1)	(74.1–95.8)	(74.2–92.2)
Europe	89.63	90.64	92.51	85.28
	(74.2–98.6)	(73.1–95.9)	(84.0–98.6)	(75.8–95.1)
North America	90.89	92.51	93.45	89.64
	(85.3–97.2)	(85.0–96.4)	(87.7–98.1)	(85.2–98.6)
South America	81.19	86.72	86.74	75.39
	(77.5–85.3)	(81.7–90.3)	(76.2–90.1)	(68.4–86.1)
1989	83.46	–	–	–
	(74.2–89.6)			
1993	88.18	86.31	91.05	80.16
	(73.4–96.5)	(73.1–94.3)	(74.1–96.3)	(72.6–86.8)
1998	92.05	90.82	94.46	91.76
	(78.2–98.6)	(82.5–96.4)	(91.2–98.6)	(83.7–93.6)

Note: Distribution range is given in (parenthesis).

Table 7. **Relative revenue efficiency**

	Model 1	Model 2	Model 3	Model 4
Combined Sample	89.44	88.31	79.03	82.60
	(76.1–97.4)	(69.1–96.7)	(56.7–97.2)	(65.0–97.7)
Asia-Pacific	85.4	83.32	72.4	76.51
	(78.5–92.9)	(75.7–92.0)	(58.0–84.3)	(69.4–96.3)
Europe	90.88	90.41	79.35	82.28
	(76.1–97.4)	(69.1–95.8)	(66.1–97.2)	(65.0–94.1)
North America	91.27	89.56	84.02	85.29
	(86.4–95.8)	(84.2–96.7)	(71.4–94.6)	(71.0–97.7)
South America	86.54	83.01	73.90	72.6
	(80.3–93.2)	(73.6–89.3)	(56.7–90.2)	(66.3–88.4)
1989	86.55	–	–	–
	(76.7–97.0)			
1993	89.95	87.43	77.94	79.11
	(84.2–95.5)	(82.1–93.1)	(58.4–90.4)	(65.0–90.1)
1998	92.23	89.57	81.34	84.06
	(85.5–96.1)	(84.6–94.4)	(59.3–97.7)	(72.2–97.8)

Note: Distribution range is given in (parenthesis).

Table 8. **Changes in cost efficiency scores**

Regions and Organisation Set Up	Combined Score	1993	1994	1995	1996	1997	1998
Combined	85.04	80.16	84.27	87.01	87.85	88.22	91.76
Asia-Pacific	80.62	82.84	81.19	83.92	84.1	84.3	85.26
Europe	85.28	84.23	85.60	86.45	88.93	90.51	93.68
North America	89.64	86.83	88.67	87.39	88.4	89.94	90.05
South America	75.39	72.64	74.71	79.82	79.86	83.25	83.76
Automated	86.69	83.92	85.01	88.39	89.07	88.84	92.65
Auction	82.21	79.17	78.92	84.03	83.85	86.22	88.36
Exchanges with Derivatives	86.34	83.21	85.31	88.92	89.03	89.07	92.73
Equity Only Exchange	82.27	79.32	82.56	86.06	85.02	86.69	89.01
Profit	89.27	83.06	86.31	88.50	89.02	90.48	92.66
Motivated Co-operative &							
Non Profit	81.06	79.55	82.62	83.91	84.56	85.01	86.48
10 Largest	85.42	85.90	86.73	87.12	87.93	87.04	90.25
Middle 10	86.06	83.68	84.12	83.23	83.32	83.80	80.23
10 Smallest	80.25	83.60	82.23	85.56	84.30	85.29	85.36

Note: Estimations are based on model 4 that accommodates additional performance measures, environmental factors and technological change.

Table 9. **Changes in revenue efficiency scores**

Regions and Organisation Set Up	Combined Score	1993	1994	1995	1996	1997	1998
Combined	82.60	79.11	84.54	82.93	83.20	83.92	84.06
Asia-Pacific	76.51	74.22	78.39	80.56	80.02	82.36	84.36
Europe	82.28	78.35	76.07	86.32	82.28	83.23	85.61
North America	85.29	82.38	84.21	84.90	86.57	87.80	93.54
South America	73.90	64.06	72.75	74.56	75.02	76.48	75.02
Automated	84.92	80.25	80.69	84.43	84.91	85.32	87.56
Auction	89.21	89.07	85.32	87.43	87.70	89.32	92.04
Exchanges with Derivatives	85.47	84.32	80.37	83.44	86.80	87.95	90.21
Equity Only Exchange	86.21	83.18	83.45	84.92	88.07	85.53	88.53
Profit	84.36	77.30	81.56	84.36	84.02	88.38	93.02
Motivated Co-operative &							
Non Profit	78.72	73.02	76.04	77.52	79.32	82.01	84.51
10 Largest	91.70	77.42	76.52	82.34	88.51	89.33	91.60
Middle 10	84.31	80.51	80.88	83.56	84.02	89.38	90.12
10 Smallest	85.94	78.33	78.54	77.57	81.36	86.32	84.29

Note: Estimations are based on model 4 that accommodates additional performance measures, environmental factors and technological change.

In respect of cost efficiency, although there is a higher cost efficiency scores for North American exchanges in most of the sample years, however, the European stock exchanges reveal a high gain of cost efficiency, 84.23% to 93.68%, over the sample period. In respect of organizational design, the average scores report a higher efficiency score for “automated” exchanges, 86.69%, over “auction” type exchanges, 82.21%. Exchanges that include derivative trades score higher than equity only exchanges while profit motivated exchanges report higher cost efficiency than the cooperative and non-profit exchanges. Among different groups, according to market capitalization size, the middle group is found to be the most cost effective one.

In the revenue efficiency estimates, the North American exchanges not only score the highest efficiency, they have also shown the most improvement over the sample years. Interestingly, the auction type markets report higher revenue efficiency, however, automated exchanges show higher improvement over the years. Exchanges with and without derivative trading facilities report almost similar scores but the exchanges that also trade derivates report higher improvement of revenue efficiency scores over the sample years. As expected, profit motivated exchanges report substantially higher revenue efficiency over other non-profit and cooperative exchanges. The largest group of exchanges show the highest average revenue efficiency scores as well as the highest changes over the sample years.

In the next step of the analysis, we focus on the correlates between cost (revenue) efficiency scores and a number of relevant organisation-specific and other related variables reflecting among other things, organizational designs, management strategy, efficiency and practices, and competitive environment (table 10 and table 11). In both estimates, we focus on the potential influence of technology cost on overall efficiency. Given the fact that technology cost information was available only for a limited number of exchanges, we report in regression 1 the estimates that include the technology cost ratio, followed by the estimates without the technology cost variable in regression model 2. Finally, we report coefficients of individual estimates of each of the independent variables as they correlate to efficiency scores in separate regression estimates. These are reported in the last two columns in both tables. We further analyse the correlation between inefficiency scores and organisational set-ups of the exchanges (eg, automated versus auction or automated auction hybrid, exchanges with derivative trading facilities versus equity only trading exchanges, and profit motivated versus non-profit exchanges), market competition (3-firm concentration and number of exchanges in the country), management strategy, efficiency and practices (recent mergers, turnover, and trading hours), and the size of the market (market index).

Table 10. **Correlates of cost efficiency**

	Regression 1		Regression 2		Separate Regressions on Each Independent Variable	
Variables/Ratios	**parameters**	**t-statistics**	**parameters**	**t-statistics**	**parameters**	**t-statistics**
Intercept	0.318	61.12***	0.450	11.48***	–	–
Technology Cost to Total Cost	0.194	1.92*	–	–	0.265	2.34**
Equity + Derivatives #	0.032	1.04	0.035	0.98	0.004	1.68*
Automated Market #	0.193	2.07**	0.024	2.04**	0.168	2.65**
Top 3 Firms' Market Share in the Exchange	–0.0001	1.83*	–0.0001	1.76*	–0.0001	1.91*
Number of Exchanges in the Country	0.013	2.02**	0.003	1.97**	0.005	1.83*
Profit Motivated #	0.044	3.21***	0.038	2.79**	0.061	2.12**
Recent Mergers #	0.005	0.64	0.007	0.51	0.004	0.82
Trading Hours Per Week	–0.018	2.29**	–0.010	2.33*	–0.004	2.00**
Turnover Ratio	–0.001	0.67	–0.001	0.54	–0.0001	0.93
Log of Market Index	–0.003	0.84	–0.003	0.80	–0.004	1.12
	Model Statistics					
Adjusted R^2	.3902		.3167		Range .0078 to .0700	
F-Statistics	4.89***		4.71***		0.6401 to 11.70	
Number of Observations	84		102		102	

Note: ***, **, * = significant at 1%, 5% and 10% significance levels respectively. # = Binary variables. Regression 1 and 2 are multiple regressions based correlation results where as the estimates in the last two columns are based on correlation estimates from regression on each of the individual independent variables. The number of observations in these estimates are 102 except for the technology cost ratio for which we have 84 observations.

Table 11. **Correlates of revenue efficiency**

	Regression 1		Regression 2		Separate Regressions on Each Independent Variable	
Variables/Ratios	**parameters**	**t-statistics**	**parameters**	**t-statistics**	**parameters**	**t-statistics**
Intercept	0.460	3.97***	0.521	5.14***	–	–
Technology Cost to Total Cost	0.001	1.60	–	–	0.001	1.75*
Listing Fee	0.052	1.48	0.054	1.63	0.059	1.17
Trading Fee	0.001	0.74	0.001	0.88	0.003	0.51
Cost Efficiency	0.099	1.43	0.106	1.38	0.046	1.77*
Equity + Derivatives #	0.063	1.81*	0.067	1.75*	0.041	1.69*
Automated Market #	0.027	1.01	0.041	1.17	0.018	1.25
Top 3 Firms' Market Share in the Exchange	–0.0008	0.82	–0.099	0.47	–0.00004	0.41
Number of Exchanges in the Country	–0.003	1.99**	–0.003	1.93*	–0.004	2.40**
Profit Motivated #	0.134	3.26***	0.105	3.02***	0.035	2.93***
Recent Mergers #	–0.029	1.09	–0.011	0.29	–0.004	0.56
Trading Hours Per Week	0.027	2.03**	0.021	2.00**	0.002	1.28
Turnover Ratio	0.0002	1.81*	0.0001	1.70*	0.0003	2.67**
Log of Market Index	0.019	2.14**	0.018	1.98**	0.0004	1.80*
	Model Statistics					
Adjusted R^2	.2130		.2425		Range –.0104 to –.0704	
F-Statistics	10.61***		9.31***		1.66 to 8.57	
Number of Observations	84		102		102	

Note: ***, **, * = significant at 1%, 5% and 10% significance levels respectively. # = Binary variables. Regression 1 and 2 are multiple regressions based correlation results where as the estimates in the last two columns are based on correlation estimates from regression on each of the individual independent variables. The number of observations in these estimates are 102 except for the technology cost ratio for which we have 84 observations.

In the cost efficiency correlates estimates (table 10), we see a positive correlation between the technology-related cost ratio and cost efficiency both in the multivariate regressions (regression 1) and single variable estimates (last two columns). Although such relationship contradicts some of the previous findings in related popular business literature where the return from technology was never found to be profitable phenomenon, however, this is consistent with recent academic literature eg Litan and Rivlin (2001), where significant savings generated by the productive use and implementation of technology. Exchanges with derivate trading do not show any significant cost efficiency relationship.[11] Automated exchange variable coefficients are found to be associated with higher cost efficiency. Exchanges with higher concentration by a few firms (3 Firm concentration ratio) report a negative correlation with cost efficiency. A positive and significant influence of NOEXCH (total number of exchanges in the country) coefficient could not support our initial view on this issue that a higher number of

[11] Alternative estimates using SETTLE, a bivariate variable representing exchanges with in-house settlement arrangements rather than forming alliances with settlement firms also show positive association with cost efficiency. However, the coefficients were not statistically significant.

competitive exchanges is likely to cause higher human capital and marketing cost resulting in lower cost efficiency. On the contrary, we see that competition from other competitors forces exchanges to become more efficient and their apparent efficiency gains outweighs any additional cost on employees or promotional activities in the increased competitive environment. As expected, the profit-motivated exchanges are associated with significant cost efficiency. Larger exchanges (INDEX) as well as busier exchanges (TURNOVER) do not report any significant relationship with cost efficiency.

In the revenue estimates (table 11), technology cost also pays off in gaining higher revenue efficiency although the statistical significance is weaker. Surprisingly, listing and trading fees have no influence on and significant correlation with revenue efficiency. This indicates that the setting of listing and trading fees are not effective tools in influencing variability in revenue efficiency. However, the cost efficiency variable indicates that being cost efficient does help in gaining positive relationship with revenue efficiency although the statistical significances in all estimates are either nonexistent or marginal. Exchanges that include derivative activities in their exchanges are found to be associated with higher revenue efficiency relative to equity only exchange sub-sample.[12] Here, we find that despite in the case of cost inefficiency, additional derivative trading activities in the same exchange pay off in terms of higher revenue efficiency.. In respect of competition variables, we find no impact of 3-FIRM variable and an inverse relationship between NOEXCH and revenue efficiency. The latter result simply confirms that despite a gain in cost efficiency from competitive environment does not necessarily mean that stronger market competition translates into more revenue efficiency. In fact, such competition hurts revenue efficiency. In both cost and revenue models, no evidence is found that recent merger initiatives are associated with greater cost or profit efficiency. It is possible that many mergers are very recent phenomena, in particular during the years 1997–1998 and that exchanges are yet to directly benefit from implicit mergers or alliances. Profit motivated exchanges and exchanges with longer working hours are associated with higher efficiency. The results also suggest that larger and efficient exchanges are more correlated with higher revenue efficiency.

In summary, the North American exchanges are reported to be most productive in respect of cost and revenue efficiency followed by the European exchanges. The European markets improved their cost efficiency tremendously during the sample years as they have taken initiatives to harmonize their regulations and adopted new technologies. Both Asia-Pacific and South American exchanges show considerable overall efficiency, however, they are not at par with

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[12] Alternative estimates using SETTLE, also show a positive and significant association with revenue efficiency scores and in all regressions but unlike the reported EQTDERIV coefficients, statistical significance is only found in the last estimate with single variable correlation.

the North American and European exchanges. Additionally, our evidence indicates that investment in technology development effectively influenced productivity. Moreover, organizational set-ups, governance, and the competitive environment are found to be significantly associated with both cost and revenue efficiency. Market size and turnover mattered more in the revenue side than the cost efficiency.

9 Conclusions

Despite increased integration and consolidation of capital markets, evolving organizational governance, alliances and regulatory changes, there is little evidence available on the performance, competitiveness, and overall understanding of the behavioral underpinnings of stock exchanges across the globe. Although a broad consensus exists that the recent growth of trading across the globe is driven by the evolving technology and the fact that exchanges are taking extra ordinary efforts to adopt and cope with some of these changes, however, nothing is known empirically to see whether adoption of new technologies yields higher efficiency for the exchanges or not. One might anticipate that investment and implementation of any such technological initiatives will result into higher efficiency, effectiveness, and the quality of operations. Such expectation is consistent with Brynjolfsson, Hitt, and Yangs' (2001) evidence on five dollars worth of market value for each dollar of installed new technology capital.

Using, an unbalanced panel data of 49 stock exchanges during the 1989–1998 period, this paper traces the productivity of stock exchanges over time and among different types and groups of exchanges. Specifically, the paper investigates among others, the impact of technology on the revenue and cost efficiency of the sample exchanges. Additionally, the paper focuses on the role of organisational type, structure, and corporate governance influencing efficiency. This is one of the first comprehensive attempts in evaluating the performances of stock exchanges assuming that the exchanges are actually operative firms (Arnold et al (1999) and Pirrong (1999)).

Our findings report the existence of substantial revenue and cost inefficiency across exchanges. On average, North American exchanges are reported to be the most cost as well as revenue efficient. European exchanges on the other hand are found to be the most improved exchanges at least in the cost efficiency category. The ongoing formation of alliances, network, and recent automation spree in the European environment probably helped in enhancing efficiency as exchanges are taking advantage of increased scale economies in all aspects. The exchanges from South America and Asia-Pacific regions are found to be substantially less efficient in all estimates. Hasan and Malkamaki (2001) report of uncoordinated regulatory norms in these two continents backed by lack of market oriented business environments.

Consistent with Domowitz and Steil (1999) and Williamson (1999), we conclude that the commitments and initiatives in technology related advancements are worthwhile and are productive endeavours as such initiatives in most cases are found to be positively and significantly associated with overall cost and revenue efficiency. Additionally, the results support the view that organizational designs and market competition are found to be significantly related to both cost and revenue efficiency. Market competition as proxied by the number of other exchanges in the same country appears to be positively associated with cost efficiency but negatively associated with revenue efficiency. Market size (market capitalization) and quality of market (turnover) are found to be important in relation to revenue efficiency where bigger and more active exchanges are correlated with higher efficiency.

Our findings are consistent with the fact that exchanges and security markets in a homogeneous regulatory environment (North American followed by the Europeans) are the most efficient institutions We also provide evidence that investments in standardization and new technologies clearly pay off in gaining productivity. Automated electronic trading systems have helped to minimize the fragmenting effect of physical distance not only on exchange formation but also on operations and services as it shows up with higher productivity in respect of cost efficiency. It is obvious from our results that money spent on technology, appropriate organizational design, network involvement, and corporate governance issues are crucial components for strategic decision-making and performance. As exchanges continue to experience various transitions and innovations, it is important that the literature views these exchanges as conventional firms and further examines their operating strategies, market environments and performances.

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