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Cross-Border Listings and Price Discovery

Evidence from UK- and US-listed Swedish Stocks

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Preface

During the writing of our master thesis, we have received help and support from several persons. We would especially like to thank Associate Professor Curt Wells for his help and insightful comments on how to get started with E-views, and Professor David Edgerton for his help and insightful comments on Error correction models. We would also like to thank our advisors Niclas Andrén and Maria Gårdängen for their academic guidance.

Lund, June 2004

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Abstract

Title Cross-Border Listings and Price Discovery: Evidence from UK- and US-listed Swedish Stocks

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Key words Price discovery, cross-border listings, cointegration, error correction model, ADR, Stockholm stock exchange, London stock exchange, Nasdaq.

Objective The objective of this study is to examine the extent to which the London stock exchange and the US stock exchange Nasdaq respectively contributes to the price discovery of Swedish stocks listed on the Stockholm stock exchange, the London stock exchange and the US stock exchange Nasdaq.

Method The study is a replicate study of the studies by Grammig, Melvin and Schlag (2000) and Eun and Sabherwal (2003). The methodology is based on the methodology of the latter study. The data material consisting of quoted stock prices for three Swedish stocks on the three stock exchanges at five-minute intervals during a 49-day-period in 2003 has been run through different statistical tests in a five-step process.

Conclusion The evidence of this study shows that prices on SSE, LSE and NASD are cointegrated and mutually adjusting. The evidence suggests that in all three cases price discovery take place on the home stock exchange SSE. Moreover, LSE contributes more to price discovery than Nasdaq

Contents

1 Introduction ... **6**
1.1 Background ... 6
1.2 Problem discussion ... 7
1.3 Objective ... 7
1.4 Delimitation ... 8
1.5 Disposition ... 8
1.6 Abbreviations ... 8
2 Theory ... **10**
2.1 Cross-border listings ... 10
2.1.1 Corporate strategies to internationalise the cost of capital ... 10
2.1.2 Implications of cross-border listings ... 11
2.2 Price discovery ... 11
2.3 Previous studies of cross-border listings and price discovery ... 12
2.3.1 Grammig, Melvin and Schlag (2000) ... 12
2.3.2 Eun and Sabherwal (2003) ... 13
2.3.3 Comparison of studies ... 14
2.4 Hypotheses ... 15
3 Institutional details ... **16**
3.1 Stock exchange presentations ... 16
3.1.1 The Stockholm Stock Exchange ... 16
3.1.2 The London Stock Exchange ... 16
3.1.2 Nasdaq ... 16
3.2 American Depositary Receipts ... 17
3.3 Company presentations ... 17
3.3.1 Electrolux ... 17
3.3.2 Ericsson ... 18
3.3.3 Volvo ... 19
4 Methodology ... **20**
4.1 Data sources and sample details ... 20
4.1.1 Preliminary data analysis ... 23
4.2 Empirical Methodology ... 25
4.2.1 Regression Analysis ... 25
4.2.2 Schwarz Information Criteria, SIC ... 25
4.2.3 Unit Root Test ... 25
4.2.4 Augmented Dickey-Fuller test ... 26
4.2.5 Cointegration, Error Correction Model and Price Discovery ... 27
4.2.6 Johansen maximum likelihood procedure ... 28
4.2.7 Error Correction Model, ECM ... 29
5 Data Analysis ... **31**
5.1 Regression Analysis ... 31
5.2 Schwarz Information Criterion ... 32
5.3 Unit Root test: Augmented Dickey-Fuller ... 32
5.4 Johansen ML Procedure ... 33
5.4.1 Statistical significance ... 33

5.4.2 Cointegration vectors 36
5.5 Error Correction Model, ECM........ 38
5.5.1 ECM Stockholm, SSE........ 38
5.5.2 ECM London, LSE........ 38
5.5.3 ECM Nasdaq, NASD........ 38
5.5.4 Alpha Coefficient........ 39
6 Conclusions........ 48
References........ 50
Appendixes........ 53

1 Introduction

In this introductory chapter, the background of the subject cross-listings and price discovery is described and followed by a problem discussion and the objective of the study. Furthermore, a disposition of the thesis is presented.

1.1 Background

The degree of globalisation and financial integration has increased substantially during recent decades. This has resulted in an increasing number of companies cross-listed on stock exchanges outside the domestic financial market.

The popularity of international cross-listings has awaked an interest with many researchers and evoked many academic studies on the subject. Most of these studies have dealt with the benefits of international cross-listings, which are considered to result in reduced costs of capital and increased liquidity of stocks. Only a few studies have covered the topic of cross-listings' contribution to price discovery. Price discovery is defined as "the process by which markets attempt to find equilibrium prices" (Harris et. al. 1995, p. 564) and is considered to be "a key function of a stock exchange" (Eun and Sabherwal 2003, p.550). Price discovery takes place on the stock exchange where the equilibrium price is determined and then spurs the prices on other stock exchanges. Bacidore and Sofianos (2002) have conducted an analysis of specialist behaviour in the American Depositary Receipt (ADR) market. ADRs are dollar-denominated negotiable instruments issued by a depositary bank which represent ownership of the underlying shares issued in the home-market. The authors state that for most ADRs, the trading volume in the home market is much larger than in the United States. They thus suggest that price discovery takes place in the home market. The study of Grammig, Melvin and Schlag (2000) focuses on German stocks listed in both Frankfurt and New York and their evidence suggests "a structure of the international equity market that has the home-market largely determining the random walk component of the international value of a firm" (p. 1). Eun and Sabherwal (2003) have examined the contribution of cross-listings to price discovery for Canadian stocks listed on both the Toronto Stock Exchange and a US exchange and their findings show that prices on the two exchanges are cointegrated and mutually adjusting.

1.2 Problem discussion

The studies performed by Grammig, Melvin and Schlag (2000) and Eun and Sabherwal (2003) show different results, as described above. For this reason, it would be useful to conduct yet another study. Furthermore, price discovery for Swedish stocks cross-listed on a foreign stock exchange has, to our knowledge, not yet been analysed. A study on the topic would therefore be useful in order to learn more about price discovery in general and about price discovery for Swedish stocks in particular. Information about in which market price discovery takes place would be interesting to investors, since it makes it possible, at least in theory, to forecast the share prices on the stock exchanges following the market in which price discovery takes place and exploit arbitrage opportunities. It would also be interesting to the companies whose stocks are listed on foreign stock exchanges. The financial marketing activities and the information flow could be directed mainly to the market in which price discovery takes place. Furthermore, this study is based on the methodology of the study written by Eun and Sabherwal (2003), published in Journal of Finance. Our study comprises three stock exchanges in contrast to two stock exchanges as in the above-mentioned studies. Thus, the model used in Eun and Sabherwal (2003) is developed in this study by the addition of one more variable. A study like this has, to our knowledge, not been performed with stocks listed on three different stock exchanges in three different countries.

The results of the study are difficult to predict. On the one hand, the domestic stock exchange is likely to contribute substantially to price discovery since the main part of the information about the company is released in the home market. On the other hand, the stock exchanges in the US and the UK are among the largest and most liquid stock exchanges in the world. For this reason, it is reasonable to assume that these stock exchanges contribute to price discovery.

1.3 Objective

The objective of this study is to examine the extent to which the London stock exchange and the US stock exchange Nasdaq respectively contributes to the price discovery of Swedish stocks listed on the Stockholm stock exchange, the London stock exchange and the US stock exchange Nasdaq.

1.4 Delimitation

The study includes three Swedish companies, namely Electrolux, Ericsson and Volvo, listed on the Stockholm stock exchange, the London stock exchange and Nasdaq. The data material consists of quoted stock prices in each market at five-minute intervals during the 49-day-period of October 9, 2003 to December 16, 2003.

1.5 Disposition

The thesis will be presented as follows:

Chapter 2: In chapter two, the theories and previous studies relevant for this thesis are presented.

Chapter 3: Details concerning the stock exchanges and companies included in the study are found in this chapter along with a description of American Depositary Receipts.

Chapter 4: This chapter presents the methodology used to conduct the study.

Chapter 5: In chapter five, the results of the different statistical tests of the data is presented and analysed.

Chapter 6: The thesis is concluded by a summary of the results along with reflections.

1.6 Abbreviations

The following abbreviations are used throughout the study:

ADF	Augmented Dickey-Fuller
ADR	American Depositary Receipt
CET	Central European Time
ECM	Error Correction Model
ELIN	Electronic Library Information Navigator
IPO	Initial Public Offering
LSE	London Stock Exchange
NASD	Nasdaq

NYSE	New York Stock Exchange
OTC	Over- the-Counter
SIC	Schwarz Information Criteria
SSE	Stockholm Stock Exchange
SSRN	Social Science Research Network
TSE	Toronto Stock Exchange
VEC	Vector Error Correction

2 Theory

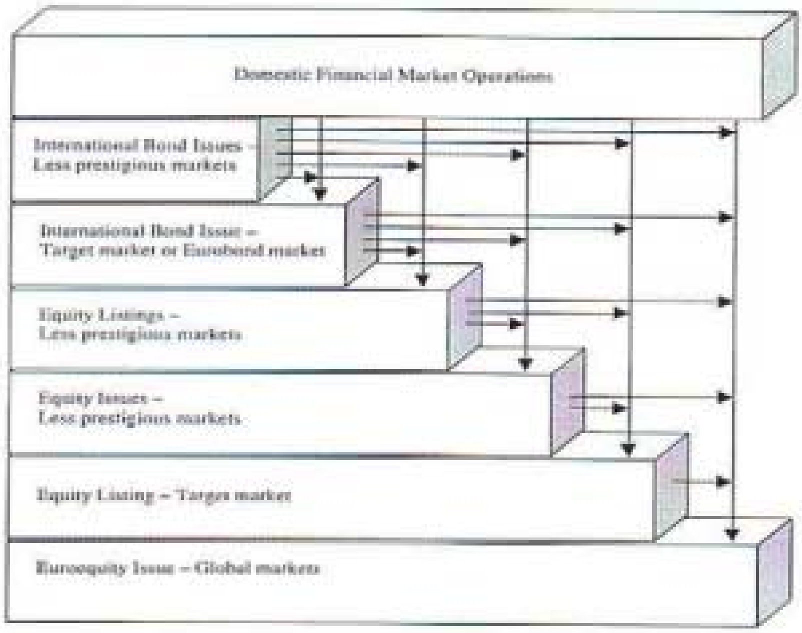
The theoretical base of the study, consisting of theories on cross-border listings and price discovery along with previous studies on the subject, is presented in this chapter. The theory-derived hypotheses of the study conclude the chapter.

2.1 Cross-border listings

2.1.1 Corporate strategies to internationalise the cost of capital

According to Oxelheim (2001), the efforts of corporations to close cross-border information gaps and internationalise the cost of capital mainly involve two strategies: the listing of the company's shares on one or more foreign stock exchanges and / or equity issues directed to investors in one or more foreign countries. The corporate strategies aimed at bridging the information gap represent a gradual process in most companies. This is demonstrated in Figure 1. Oxelheim (2001) suggests that a company that wishes to avoid a failure to raise capital on its target market should follow the route on the left side of the figure, thereby gradually gaining experience and recognition.

Figure 1. Major corporate strategies for eliminating cross-border information asymmetries in internationalising the cost of capital. Source: Oxelheim (2001), s. 196.



2.1.2 Implications of cross-border listings

The academic literature on the economic implications of the corporate decision to list shares on a foreign stock exchange is extensive. Karolyi (1998) has surveyed the studies and the evidence shows that:

- Share prices increase in the month around the cross-listing, whereas the post-listing price performance up to one year is negative on average, but varies widely across companies depending on home and listing market, capitalisation and capital-raising needs and other company-specific factors. In most studies, the post-listing price decline is explained by the management timing idea, which suggests that management times the listing to follow good performance, or by the fact that listing companies tend to be large, mature, non-growth oriented companies.
- The total trading volume increases on average after the listing and home-market trading volume often increases also.
- The exposure to domestic market risk is significantly reduced, while the exposure to global market risk and foreign exchange risk increases only slightly. Conservative estimates indicate that international equity diversification around cross-listings can result in a net reduction in the cost of equity of about 126 basis points.
- The liquidity of trading in shares improves overall. Typically, the total trading volume increases and the home-market spreads decrease, which can be explained mainly by the competition from the new market. However, the extent to which the liquidity improves, is dependent on the increase in total trading volume, the listing location, the proportion of the total trading volume that is captured by the new market and the foreign ownership restrictions in the home market prior to the cross-listing.

2.2 Price discovery

Schreiber and Schwartz (1986) argue against that one might think that the “correct” price for a share on a market must be between the highest bid price and the lowest ask price, for a continuous market, or where an aggregate buy function crosses an aggregate sell function, for a call market. The authors are of the opinion that this is not correct, since orders submitted to a market reflect the investors’ expectations regarding the prices they are likely to transact at. These expectations depend on the current market conditions. Taking the effect of expectations on orders submission into account, the true equilibrium price does not need to fall within the spread for a continuous market or be at the cross for a call market.

When Schreiber and Schwartz (1986) describe the workings of the price discovery process, they observe that “the advent of new information will generate a succession of trades and price changes while traders digest the news, including price movements, and the market searches for a new equilibrium price” (p. 44). The authors suggest that price discovery is not instantaneous. In other words, an equilibrium price exists in the market to start with. Once new information occurs, the price fluctuates for a while until a new equilibrium price is set.

To explain price discovery related to this study, an assumption is made that the home market, in this case the Stockholm Stock Exchange, spurs the prices of the Swedish stocks. When a change in price occurs on the SSE, the other stock exchanges, in this case the London Stock Exchange and Nasdaq, respond and are trying to catch up the divergence in price between SSE and the other exchanges. However, if the price would change on LSE or Nasdaq, SSE would not respond to the change. In short, this means that price discovery takes place on the stock exchange where the equilibrium price is determined and then spurs the prices on other stock exchanges.

This is a rather similar process to the American thinker Thomas Kuhn’s view of the universe; first a paradigm exists, then anomalies (facts that do not fit in the paradigm) occur, which leads to a crisis. Next, there is a scientific revolution, where the new paradigm is accepted and the old paradigm is abandoned. The new paradigm is established as normal science. Then, new anomalies occur and the process starts over. Kuhn (1962) proposed that paradigm shifts, rather than scientific method, actually advance science.[1]

2.3 Previous studies of cross-border listings and price discovery

2.3.1 Grammig, Melvin and Schlag (2000)

The study by Grammig, Melvin and Schlag examine three large German firms that are cross-listed on the Frankfurt Stock Exchange and the New York Stock Exchange (NYSE). DaimlerChrysler is a global registered share, while Deutsche Telekom and SAP are listed as ADRs on NYSE. Using a high-frequency sample

[1] Thomas Kuhn (1922-1996) was an American historian and philosopher of science, a leading contributor to the change of focus in the philosophy and sociology of science in the 1960s. He taught at Harvard, the University of California Berkeley, Princeton University and Massachusetts Institute of Technology (MIT).

of quotes from both stock exchanges during the overlap of trading hours along with the dollar/euro exchange rate, the study addresses two questions: where does price discovery occur for internationally-traded firms and how do international stock prices adjust to an exchange rate shock?

The results of the study suggest a structure of the international equity market that has the home-market largely determining the random walk component of the international value of a firm along with an independent role for exchange rate shocks to affect prices in the derivative markets. The results support the notion that price discovery occurs largely in Frankfurt. However, the results differ across the three firms studied. In the case of DaimlerChrysler, there is a significant information share for NYSE. There is an even bigger role for NYSE when it concerns SAP.

For Deutsche Telekom, almost all revenues are generated in Germany, while DaimlerChrysler and SAP both have substantial revenue sources in the US. With this in mind, the authors argue that “it makes intuitive sense that multinational firms would have more room for international price discovery than firms that are essentially operating only in their home market” (p.19).

Concerning the question of exchange rate shocks, the authors find that nearly all of the adjustments occur through the NYSE price.

The study clearly shows an initial effect in intensity on the Frankfurt Stock Exchange when NYSE opens, as well as a fall in intensity on the NYSE when Frankfurt closes.

2.3.2 Eun and Sabherwal (2003)

The study of Eun and Sabherwal, that was published in The Journal of Finance in April 2003, examines the contribution of cross-listings to price discovery for 62 Canadian stocks listed on both the Toronto Stock Exchange (TSE) and in the US in the form of ordinary shares on the NYSE, American Stock Exchange (AMEX), or Nasdaq. The sample period was the six-month period of February to July 1998. For each stock, two price series was formed using quoted stock prices in each market at ten-minute intervals. The trading time on the TSE and the US stock exchanges coincides and the overlap is thus perfect. Further, Eun and Sabherwal used unit root tests and cointegration tests to analyse the data. The results of the study show that prices on the TSE and the US exchange are cointegrated, with equality of prices holding as an equilibrium relationship. Further, the adjustments that maintain equality occur on both exchanges, that is, the US prices adjust to the

TSE prices and vice versa. Thus, it was shown that the US market contributes to the price discovery of the Canadian stocks in the sample. The findings further showed that the TSE is dominant for a majority of the firms, but that there are many firms for which the US exchange's contribution to price discovery is larger than that of the TSE.

2.3.3 Comparison of studies

In the table below, a comparison of the above-mentioned studies is presented. The table reappears in the conclusions in chapter 6 supplemented by the details of this study.

Table 1. Summary and comparison of studies

	Canadian study	**German study**
Authors:	Eun, Sabherwal	Grammig, Melvin, Schlag
Published in:	Journal of Finance, 2003	(Working paper, 2000)
Stock exchanges included:	Toronto Stock Exchange New York Stock Exchange Nasdaq American Stock Exchange	Frankfurt Stock Exchange New York Stock Exchange
Firms included:	62 Canadian firms	3 German blue chip firms[2]
Time period:	6 months (February-July 1998)	3 months (August-October 1999)
Intraday time interval:	10 minutes	5 minutes
Overlap trading time:	Perfect overlap	1,5/ 2 hour overlap
Share type:	Ordinary shares	ADRs and ordinary shares
Findings:	This study finds that prices on the TSE and the US exchange are cointegrated and mutually adjusting. For 58 of the 62 firms, the Canadian prices respond to deviations from the US prices. Both the TSE and the US exchange contribute to price discovery.	The evidence of this study suggests that price discovery takes place mainly in the home market, that is in Frankfurt. The home market largely determines the random walk component of the international value of the companies. However, the result differs across the stocks. For example, for one of the companies included in the study, 20% of the price innovation is determined on NYSE.

[2] Blue chip firm: low risk shares in good companies

2.4 Hypotheses

Bacidore and Sofianos (2002) have conducted an analysis of specialist behaviour in the American Depositary Receipt (ADR) market and state that for most ADRs, the trading volume in the home market is much larger than in the United States. They thus suggest that price discovery takes place in the home market. Thus, the first hypothesis of the study states that:

H_1: Price discovery of the Swedish stocks takes place in the home market, which is on the Stockholm Stock Exchange.

Furthermore, for the three Swedish stocks in this study, the trading volume on the London Stock Exchange is larger than that on Nasdaq, which induces the following hypothesis:

H_2: The extent to which the London Stock Exchange contributes to the price discovery of the Swedish stocks is greater than the extent to which Nasdaq contributes to the price discovery of the same stocks.

3 Institutional details

This chapter contains presentations of the stock exchanges and companies that are included in the study and a description of American Depositary Receipts.

3.1 Stock exchange presentations

3.1.1 The Stockholm Stock Exchange

The Stockholm Stock Exchange (SSE) is an auction market. The total turnover value and total market value for the shares traded on the A-list, O-list and the Xternal list in 2003 was approximately 2,453 billion SEK and 2,314 billion SEK respectively. The number of listed companies on the lists mentioned above amounted to 297. The trading hours for shares on SSE are 9.30 – 17.30 Central European Time (CET). (Stockholm Stock Exchange homepage)

3.1.2 The London Stock Exchange

The London stock exchange (LSE) is an auction market. The number of listed companies in 2003 amounted to 2 311 companies of UK origin and 381 companies of international origin. The total turnover value and total market value for the UK companies was 1 877 billion GBP and 1 374 billion GBP respectively. The equivalents for the international companies were 1 759 billion GBP and 1 975 billion GBP. The opening hours on the LSE are 9 – 17.30 CET. (London Stock Exchange homepage)

3.1.2 Nasdaq

In 1971, the National Association of Securities Dealers made available to dealers and brokers in the over-the-counter, OTC, market an automated quotation system called the National Association of Securities Dealers Automated Quotation system, the NASDAQ system. The dealers communicate with each other by telecommunications equipment such as wires, computers and telephones. Investors get in touch with dealers when they want to make a trade and can negotiate a deal. (Ross et al 2002)

The opening hours on Nasdaq are 9 – 16 US Eastern Time, which corresponds to 15 – 22 CET. (Nasdaq homepage)

3.2 American Depositary Receipts

The three firms in this study are all traded in the form of American Depositary Receipts (ADRs) on Nasdaq. This dollar-denominated US trading is not an exchange of actual shares of the firms, but rather trade in negotiable instruments issued by a depositary bank that represent ownership of the underlying shares issued in Sweden (Grammig, Melvin, and Schlag 2000).

Since ADRs are issued at a fixed multiple relative to the underlying shares, they tend to trade in a very limited range around the price of the underlying share, exchange rate adjusted. ADRs and underlying shares are close, but not perfect, substitutes. ADRs are priced in US dollars and trade and settle as any other stock in the United States. The dollar price will differ from the home market price because of the exchange rate. Part of the differential between the prices of the ADR and the home market share is also due to exchange rate risk.

There are other alternatives than ADRs for companies that are cross-listed overseas, for example Global Registered Shares (GRS). One example is DaimlerChrysler AG (Karolyi 1999), which in 1998 got a single global registered share certificate on stock exchanges around the world. The GRS quotes, trades and settles in US dollars on the NYSE and in Euros on the Frankfurt Stock Exchange through a new global share registrar linking German and US registrars and clearing facilities.

The actual share of the firm in the issuing country is called home market share, common share or ordinary share.

3.3 Company presentations

3.3.1 Electrolux

Electrolux is the world's largest producer of appliances and equipment for kitchen, cleaning and outdoor use and one of the largest producers in the world of similar equipment for professional users. The largest owner of Electrolux is Investor (The Electrolux homepage).

The Electrolux A- and B-shares are listed in Stockholm since 1930 under the ticker codes ELUX A and ELUX B. The B-shares are also traded on the London stock exchange since 1928 under the symbol ELXB. Furthermore, the Electrolux shares are traded in the United States since 1987 in the form of ADRs on Nasdaq, under the symbol ELUX. One ADR corresponds to two B-shares. During 2003, the Electrolux share was delisted from the exchanges in Paris and Zürich (The Electrolux homepage).

In 2003, a total of 611 million Electrolux shares were traded on the various stock exchanges. 78,5 percent of these were traded on the Stockholm stock exchange, 21 percent on the London stock exchange, and 0,5 percent within the Nasdaq system (Electrolux Annual Report 2003).

3.3.2 Ericsson

Ericsson is the largest supplier of mobile systems in the world and provides total solutions covering everything from systems and applications to services and core technology for mobile handsets. With Sony Ericsson, the company is also a supplier of complete mobile multi-media products. The largest owner of Ericsson is Investor (The Ericsson homepage).

Ericsson's A- and B-shares are traded on the Stockholm Stock Exchange under the tickers ERIC A and ERIC B. A-shares each carry one vote and B-shares each carry one-thousandth of a vote. The B-shares are also traded on the exchange in London under the ticker code ERI. Furthermore, Ericsson shares are traded in the form of ADRs on Nasdaq, under the symbol ERICY. Each ADR represents ten B-shares. During 2003, Ericsson delisted from the exchanges in Düsseldorf, Frankfurt, Hamburg and Paris and from the Swiss Exchange (The Ericsson homepage).

More than 69 billion shares were traded in 2003, of which about 74,5 percent were traded on the Stockholm Stock Exchange, 12,8 percent on Nasdaq, and 12,6 percent on the London Stock Exchange. Trading on other exchanges amounted to less 1 percent of the total (Ericsson’s Annual Report 2003).

3.3.3 Volvo

The Volvo Group is one of the world's leading suppliers of transport solutions for commercial use, such as trucks, buses and construction equipment. The largest owner of Volvo is Renault (The Volvo Group homepage).

The Volvo A- and B-shares are listed on the stock exchanges in Stockholm and London. The ticker codes are VOLV A and VOLV B on the Stockholm stock exchange and VOLA and VOL on the London stock exchange. The shares are also traded in the form of depositary receipts in Frankfurt, Hamburg and Düsseldorf, and in the form of ADRs on Nasdaq, under the symbol VOLVF. One ADR represents one B-share (The Volvo Group homepage). Volvo recently delisted from the exchange in Brussels (The Stockholm stock exchange).

In 2003, 542 million shares were traded in total. About 80,5 percent of the total number of shares were traded in Stockholm, while 17,6 percent and 1,9 percent respectively were traded in London and on Nasdaq respectively (The Volvo Group Financial Report 2003).

4 Methodology

In this chapter, the methodology used to conduct the study is presented.

A quantitative approach is used for this study, due to the fact that the study is based on a very high number of intraday trade data and intraday exchange rates data. The quantitative approach is characterized by a focus on the collection of numerical data and the use of statistical tools to analyze the data. The method is more formalised and structured than a qualitative method (Holme and Solvang, 1997). Furthermore, the result of a quantitative study might be applicable to a larger population than the one included in the study or can be used as a replicate for future studies. Moreover, the study is of deductive character since hypotheses are used. (Bryman, 1997)

This study is a replicate of two previous studies. The first study is “Cross-Border Listings and Price Discovery: Evidence from US-Listed Canadian Stocks”, written by professor Cheol S. Eun and professor Sanjiv Sabherwal and published in the Journal of Finance in April 2003. The second study is “Price Discovery in International Equity Trading”, written by Joachim Grammig, Michael Melvin, and Christian Schlag, which is a working paper[3]. A replicate study can be used to discover to what extent a result of a previous study can be significant in another environment (Bryman, 1997).

4.1 Data sources and sample details

As mentioned above, this study is a replicate study of two previous studies, which naturally were the starting point. After reading these studies carefully, a search for related articles and relevant theories was processed in the library search engines such as ELIN and in Internet databases like SSRN.[4]

The selection of the companies to be included in the study was made from a large population and included several steps, so it is well founded to present every step of the process. In the end of 2002, 297 companies were listed on SSE (Stockholm Stock Exchange homepage). After contacting the Stockholm Stock Exchange’s information desk, a list of companies that were listed both in Stockholm and on at

[3] Can be found and downloaded on www.SSRN.com

least one other stock exchange in another country was received. There were 31 companies on the list. After reading previous studies on price discovery, five qualification criteria were decided on, which the companies to be included in the study had to live up to.

The five qualification criteria:

1. The company must be Swedish in terms of having Stockholm as its home stock exchange.
2. The company must be listed on at least SSE, LSE and Nasdaq to fulfil the purpose of the thesis.
3. The company's stock should not have been subject to any splits or IPOs during the sample time period.
4. The company should not have been subject to any mergers or acquisitions that resulted in major changes in the company structure during the sample time period.
5. There should be substantial volumes in the trade of the company's stock on the three stock exchanges mentioned in 3.

In the first step, 19 companies were not Swedish and were thus excluded, which resulted in a remaining population of 278 companies. In the second step, 274 companies were eliminated, which left us with 4 companies. One of these companies was excluded since it failed the last criterion[5].

Finally, there were three companies left that lived up to all five qualifications. Hence, a total of 294 companies were eliminated. The three companies that fulfilled the five qualification criteria were Electrolux, Ericsson and Volvo. The next step was to start investigate how the data needed for the study could be obtained. The previous studies had used the Trade and Quote database (TAQ), but this was not available at Lund University and too costly for us to subscribe for. After considering different options, the choice fell on the Bloomberg system[6], through which data for up to 50 business days can be downloaded with a 5-minute interval. If the download takes place during trading hours, you will end up with 49 full business days of data, and the study thus has 49 full business days of data for Stockholm and London. Nasdaq was closed for Thanksgiving on November 27, 2003 and the study thus has 48 days of data for Nasdaq.

The download of the data took place on December 17, 2003 and included data from October 9 to December 16, 2003. This is a good period in the sense that

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[4] ELIN, Electronic Library Information Navigator, is available at Lund University and SSRN, Social Science Research Network, is a database for working papers, see http://www.ssrn.com

[5] The last company to be excluded was SKF, which in a press release stated the intention to de-list their stock from Nasdaq due to insufficient volumes in the trade of the stock.

[6] The version used was Bloomberg Professional, which is available at Lund University.

there were no major holidays, no stock market crashes and no other important events, like terrorist attacks, taking place. The download included data for all three stocks from all three stock exchanges as well as the SEK/USD rate and the SEK/GBP rate (with 5-minute intervals). During the sample period, the highest rate of SEK/USD was 7.90 SEK and occurred on November 4, 2003. The lowest rate was 7.29 SEK and occurred on December 9, 2003. For SEK/GBP, the highest rate was 13.27 SEK and occurred on November 3, 2003 and the lowest rate was 12.61 SEK and occurred on October 9, 2003. The data consists of quoted prices and not transaction prices, since quotes are updated even if no transaction has taken place. The previous studies are also based on quoted prices.

When the download was completed, full business days were received on each stock exchange for the stocks. Only the overlapping time between the different stock exchanges for each trading day is needed for the study. Thus, data was excluded, in order to end up with data for the overlapping trading hours only. The overlapping trading hours for Stockholm stock exchange and Nasdaq is 2.5 hours between 15.00-17.30 CET. The overlapping time between London stock exchange and Stockholm stock exchange is 7.5 hours between 09.30-17.00 CET. Nasdaq's and London stock exchange's overlapping trading hours is 2 hours between 15.00-17.00 CET.

The download included Ask quotes, which included both bid and ask quotes, and Bid quotes, which included both bid and ask quotes, for both share prices and exchange rates. The total amount of data downloaded can be estimated to around 210 000 observations. Adjusted for overlapping trading hours, the total amount of data can be estimated to around 150 000 observations.

All the data was examined to make sure that it contained share prices and exchange rates for every 5-minute interval, which was a very demanding and time-consuming task. A few observations were missing here and there. We contacted the Bloomberg support desk in London to find out why and their interpretation of this was that "no trade had occurred, the bid and ask quotes had not changed and that volume was zero" (Mr. Cail, Bloomberg, December 30, 2003).

A calculation of the average of the Ask quotes and the average of the Bid quotes were made. Then an average of the Bid and Ask was calculated ((Average Ask * Average Bid) / 2). The total amount of observations was now narrowed down to around 37 500:

Nasdaq:	(2,5 hours * 12 observations/hour * 48 days * 3 stocks)	= 4 320
London:	(7,5 hours * 12 observations/hour * 49 days * 3 stocks)	= 13 230
Stockholm:	(8 hours * 12 observations/hour * 49 days * 3 stocks)	= 14 112
SEK/USD:	(2,5 hours * 12 observations/hour * 48 days)	= 1 440
SEK/GBP:	(7,5 hours * 12 observations/hour * 49 days)	= 4 410
Total:		**= 37 512**

Finally, the share prices was converted into SEK and adjusted for the relationship between ADRs and shares.

4.1.1 Preliminary data analysis

After the necessary adjustments of the data material had been made, the statistical tests could be performed. The statistical program Eviews 4.0 was used. To be able to perform the tests, we had to learn Eviews[7], which we had never used, and we had to learn both basic and advanced econometrics, a highly time consuming task. The study uses the same order of the statistical tests as Eun and Sabherwal (2003) and Grammig, Melvin and Schlag (2000). The order was the following:

1. Run basic regressions to make sure the data is valid and reliable
2. Test for lags using the Schwarz Information Criteria (SIC)
3. Run Augmented Dickey-Fuller test (ADF) to test for unit roots
4. Run Johansen Cointegration Test to see if variables cointegrate with each other and
5. Write Error correction model (ECM) equations and perform Vector error correction test (VEC) to see where and to what extent price discovery takes place.

Each of the above steps are dependent of its preceding step. If one test fails, you cannot proceed with the next test.

First, a regression analysis was made to be certain that the data was statistically significant and valid, which it was when looking at r^2 and adjusted r^2, t-values and probability (see table 2 in 5.1 for the test values).

Next, the optimal number of lags for each stock on each stock exchange was tested. The optimal number of lags was needed for the Johansen Cointegration Test, which was performed later. To test for the optimal number of lags, the Schwarz Information Criteria, SIC, was used. The lags are optimal when the SIC are at the lowest value. Note that SIC can be negative. The SIC was used, since it

[7] We are greatly thankful to Associate Professor Curt Wells for his help and his insightful comments on how to get started with Eviews.

is a better test than Akaike information criterion, AIC, when the number of observations is very large (Enders, 2004). The starting point was 12 lags, which gives one observation per hour, and the number of lags was reduced down to one lag to see when SIC was at the lowest value and probability at the highest value. The optimal number of lags for each stock on each stock exchange is presented in table 3 in section 5.2.

After having received the appropriate lag length of each stock and each stock exchange, the Augmented Dickey-Fuller test (ADF) was performed, which is a unit root test (see test result in table 5 in 5.3). The ADF test will be further explained in section 4.2.2.

The next step in the series of statistical tests is the Johansen Cointegration Test. This test is performed to see if two or more variables cointegrate with each other. If cointegration does not exist, markets would not be efficient and there would be arbitrage opportunities. Also, performing the last test, Error correction model, would be meaningless. In the Johansen Cointegration test, multiple regressions are performed to see if, for example, the price of an Ericsson share in Stockholm cointegrated with the prices in London and/or on Nasdaq. Moreover, the cointegrating vector values received from the Johansen cointegration test are used in the final error correction model equations as beta values (see 5.4).

The final test in the study is an Error correction model, ECM.[8] After looking into the ECMs used in Eun and Sabherwal (2003) and Grammig, Melvin and Schlag (2000), the ECM in the first study were found to be more comprehensive than the ECM in the second study. Furthermore, the first study has been published in the Journal of Finance while the second study is a working paper. Thus, a decision was made to follow the approach of Eun and Sabherwal (2003). From their ECM, we developed and wrote our own equations with one additional stock exchange included compared to their two stock exchanges. The ECM in this study is more developed and extended versions of the normal, two-variable, regression equation. The ECM equations for this study are presented in section 5.5.

[8] We are greatly thankful to Professor David Edgerton for his help and insightful comments on Error correction models.

4.2 Empirical Methodology

4.2.1 Regression Analysis

In a regression analysis, the objective is to estimate the value of a continuous output variable from some input variables. A line in a two dimensional or two-variable space is defined by the equation $Y=a+b*X$ where the Y variable can be expressed in terms of a constant, a, and a slope, b, times the X variable. The constant is also referred to as the *intercept*, and the slope as the *regression coefficient* or β *coefficient* (Andersson et al 1994). This study has one stock exchange as dependent variable (Y) and the other two stock exchanges as independent variables (X). The regression analysis is used to test the data to make sure it is statistically significant, among others R square (r^2), standard error and t-statistics is used. Six separate regressions with Stockholm Stock Exchange, SSE, as dependent variable is performed for all three stocks, since SSE is the companies' home stock exchange. The results are presented in table 2 in section 5.1.

4.2.2 Schwarz Information Criteria, SIC

To test for the appropriate number of lags, the Schwarz Information Criteria, SIC, can be used. The argument for using this criterion instead of Akaike information criterion, AIC, in this study is that SIC is a better criterion when the number of observations is very large. A lag is used to predict the dependent variable Y at time t-1. For example, a change in price today will not only depend on the current prices, but on past prices as well. The lags are optimal when the SIC are at the lowest, note that SIC can be negative. (Enders 2004)

4.2.3 Unit Root Test

This study is based on observations of intra-day stock prices, variable y_t. The variable is random since it cannot be perfectly predicted; you can never know the value of the intra-day stock prices until it is observed (Hill et al, 2001). In this study, it is assumed that the log of the home-market share prices, the Nasdaq share prices and London share prices evolves as a random walk, the coefficient (α) might be exactly one. This means that the current stock price (y_t) should be equal to last period's price plus a white-noise term (ε_t).

$$y_t = \alpha y_{t-1} + \varepsilon_t \qquad (1)$$

Nelson and Plosser (1982) presented evidence that macroeconomic data are non-stationary; for example, hourly stock prices have very often been proven to be non-stationary. Engel and Granger (1987) introduced the theory of spurious regressions. They stated that there is a danger of obtaining apparently significant regression results from uncorrelated data when using non-stationary time series in a regression analysis. However, there is an exception to this rule. If Y_t and X_t are two random walks, and hence are non-stationary, I(1) variables, then their differences or any linear combination of them such as $e_t = y_t - \beta_1 - \beta_2 x_t$ should be I(1) as well. Yet, the two series may have the property that a particular linear combination of them is stationary. Moreover, if $e_t = y_t - \beta_1 - \beta_2 x_t$ is a stationary, I(0), process then y_t and x_t are said to be cointegrated. This means that the variables share the same random walk component and their difference, e_t, is stationary. The cointegrated variables y_t and x_t exhibit a long-term equilibrium relationship.

The stationary of a time series can be tested directly with a unit root test. In this study, an augmented Dickey-Fuller test is used. The Autoregressive model, AR(1) model for each of the price series from Stockholm-, Nasdaq- and London stock exchange is the above (1) equation, where ε_t is a white noise with zero mean and constant variance $ó^2_\varepsilon$. If the coefficient equals one, α=1, then y_t is a non-stationary random walk. $y_t = y_{t-1} + \varepsilon_t$, and is said to have a unit root (Ramanathan 1995).

4.2.4 Augmented Dickey-Fuller test

A Dickey-Fuller test is an econometric test used to test whether a certain kind of time series data has an autoregressive unit root. An augmented Dickey-Fuller test is a version of the Dickey-Fuller test for a larger and more complicated set of time series models. It includes lagged first differences of the price series in the equation, to test for the presence of a unit root (Hill et al 2001).

When performing an ADF test, each price series are tested separately. The test is used to prove with statistical significance that each price series has a unit root and is not cointegrated. This is needed for the next step in the study when we perform the Johansen ML procedure where all price series are integrated to one equation. In this test the price series together should be cointegrated and stationary.

Three different equations can be used to test the presence of a unit root. The difference between the three equations concerns the presence of deterministic elements b_0 and b_2t. In all ADF tests, X is a residual of the estimated long-term relationship. If X is stationary, then the price series is stationary. The null hypothesis in all three cases is that β equals zero. If null can be rejected, the X_t price series contains a unit root (Dickey and Fuller 1979).

$H_0 \rightarrow$	$\beta = 0$	Unit Root and No Cointegration
$H_0 \rightarrow$	$\beta < 0$	Stationary and Cointegration

For each price series in this study the following three equations are considered.

$$\Delta X_t = \beta X_{t-1} + \sum \phi_i \Delta X_{t-1} + \varepsilon_t \quad (2)$$

The above equation is the simplest model of ADF. It tests if X is a pure Random Walk. If the t-statistics is outside the confidence interval, the hypothesis is rejected.

$$\Delta X_t = b_0 + \beta X_{t-1} + \sum \phi_i \Delta X_{t-1} + \varepsilon_t \quad (3)$$

The above equation tests if X is a Random Walk with Drift. In this test t-statistics and F-statistics are used.

$$\Delta X_t = b_0 + \beta X_{t-1} + b_2 t + \sum \phi_i \Delta X_{t-1} + \varepsilon_t \quad (4)$$

The above equation tests if X is a linear time trend. In this test, t-statistics and F-statistics are used.

4.2.5 Cointegration, Error Correction Model and Price Discovery

Engle and Granger (1987) provided the cornerstone research linking cointegration series that move together to the concept of Error Correction Model, ECM. However, Engle and Granger’s two-step procedure has been shown to be most appropriate for series with only two variables with one possible cointegration vector (Enders 2004). Harris et al suggests that the cointegration test by Johansen (1988) is preferred in the more practical cases with several variables, which will be used in this study to estimate the cointegrating vector for each firm. The concept of cointegration becomes relevant when the price series studied are non-stationary I(1).

There is a possibility that one variable in a system of several cointegrated series is independent within the error correction process. This motivates the use of ECM in evaluating price discovery, since the cointegrating vectors define the long-run equilibrium, while error correction dynamics characterize the price discovery process. (Eun and Sabherwal 2003) For example, if the price of the Ericsson share listed on the London Stock Exchange responds to deviations from the Stockholm Stock Exchange, but the Ericsson share price on the Stockholm Stock Exchange does not respond to deviations from the London Stock exchange, that would be evidence that the price discovery process of the Ericsson share is focused in Stockholm.

4.2.6 Johansen maximum likelihood procedure

The finding that many macro time series may contain a unit root, has spurred the development of the theory of non-stationary time series analysis. Engle and Granger (1987) pointed out that there is a possibility that a linear combination of two or more non-stationary series may be stationary. If such a stationary linear combination exists, the non-stationary time series are cointegrated. The stationary linear combination, the cointegrating equation, may be interpreted as a long-run equilibrium relationship among the variables. For example, consider a set of variables in long-run equilibrium where: $\beta_1 x_{1t} + \beta_2 x_{2t} + \ldots + \beta_n x_{nt} = 0$. The equilibrium error is $\mathbf{e_t = \beta' x_t}$. If the equilibrium is meaningful, the error is stationary. Engle and Granger's (1987) definition of cointegration is:

> The components of the vector x_t are said to be cointegrated of order d,b denoted by $x_t \sim CI(d,b)$ if:
> 1. All components of x_t are integrated of order d.
> 2. There exists a vector β' such that the linear combination $\beta' x_t$ of order (d-b) where b> 0. β' the cointegrating vector.

As discussed above, Johansen ML procedure is used in this study, since the study has several variables. The purpose of a cointegration test is to determine whether a group of non-stationary series are cointegrated or not, and if so to determine the cointegration vector. The basic idea behind Johansen ML procedure is to estimate the AR model augmented with lags of the first difference series and deterministic terms and obtain a well-specified multivariate autoregressive representation with multivariate white noise error. (Enders 2004) In Johansen's cointegration test the null hypothesis is that there is no cointegration. That is, we maintain that there is no long-run relationship, which is the opposite of unit root tests, where the null hypothesis is that there is a unit root. (Johansen 1988)

The Johansen ML procedure test of the hypothesis:

$H_0 \rightarrow \beta = 0$ Stationary and Cointegration

$H_0 \rightarrow \beta < 0$ Unit Root and No Cointegration

A very important insight of Johansen is that the rank of π (π= the matrix) can be used to determine whether or not two variables are cointegrated (Johansen 1988). When using Johansen ML procedure, it is possible to do the following:

1. Estimate an error correction model
2. Determine the rank of π. For example, if $\pi = 1$, there is a single cointegration vector and the expression πx_{t-1} is the error-correction term. In other cases in which $1< \pi < n$, there are multiple cointegration vectors.
3. Test restrictions on the cointegration vector. For example, Johansen defines the two matrices α and β, both of dimensions (n * r) where r is the rank of π. The properties of α and β are: $\pi=\alpha\beta'$, where β is the matrix of cointegrating parameters and α can be seen as the matrix of the speed of adjustment parameters. In this study, α can for example tell us how fast Nasdaq responds to a change on Stockholm stock exchange. (Enders 2004)

4.2.7 Error Correction Model, ECM

In this study, the error correction approach used by Harris et al. (1995) is used. This approach was also used by Eun and Sabherwal (2003), but this study differs from Eun and Sabherwal in one way; this study includes one more variable. The reason for this is that price discovery is studied on three stock exchanges rather than two, like the previous mentioned studies.

An alternative approach to Harris et al. (1995) is the Hasbrouck (1995) approach. This approach looks for common stochastic trends between price series. In the Hasbrouck approach, a market's contribution to price discovery is measured as the market's relative contribution to the variance of the innovations in the common trend. The contribution is termed a market's information share. The Hasbrouck approach requires prices to be ordered, since it involves Choleski factorization of the covariance matrix of the innovations in prices of different exchanges. As a consequence of this, the information shares are not unique, since they depend on the ordering of prices. The Hasbrouck approach was used with modification in the study performed by Grammig, Melvin and Schlag (2000). We find that the error correction approach of Harris et al. is more appropriate in our study.

The principle behind ECM is that long-term cointegration equilibrium exists, but in the short-run, disequilibrium may exist. In an error correction model, the short-term dynamics of the variables in the system are influenced by the deviation from equilibrium. With the error correction mechanism, a portion of the disequilibrium in one period is corrected in the next period. (Maddala 2001)

In this study, a vector error correction model is used. *"A VEC model is a restricted vector autoregression model, VAR, designed for use with non-stationary series that are cointegrated. The VEC has cointegration relations built into the specification so that it restricts the long-run behavior of the endogenous variables to converge to their cointegrating relationships while allowing for short-run adjustment dynamics"* (Eviews 4.0 users help guide).

Engle and Granger (1987) showed that if two price series x_t and y_t are cointegrated, the short-term disequilibrium relationship between them can always be expressed in the error correction form:

$$\Delta X_t = \mathrm{p}_1 Z_{t-1} + \text{lagged}\left(\Delta x_t, \Delta y_t\right) + \varepsilon_t \qquad (5)$$

The above equation is known as the Granger representation theorem.[9] The theorem should hold if x_t and y_t are cointegrated, so that P_t is stationary. This means that previous departures from equilibrium must be forced back; this is what an error correction model implies. (Engle and Granger 1987)

There is a relationship between the error correction models and cointegrated variables. By assumption, ΔX_t is stationary, I(0). This means that the right hand side of X also has to be I(0) in order for the equation to make any sense. Given that ε_t is stationary, then the linear combination of $p_1 Z_{t-1}$ + *lagged* $(\Delta x_t, \Delta y_t) + \varepsilon_t$ must also be stationary, hence the linear combination must be cointegrated with a cointegrating vector, β. The essential point to note is that the error correction model necessitates that the two (could be more) variables be cointegrated of order CI(1,1). This results in a general error correction model including lagged changes of each variable:

$$\Delta P_{\mathrm{t}}^{\mathrm{SSE}} = \mathrm{a}_0^{\mathrm{SSE}} + \alpha^{\mathrm{SSE}} \left(P_{t-1}^{\mathrm{SSE}} + \beta^{\mathrm{LSE}} P_{t-1}^{\mathrm{LSE}} + \beta^{\mathrm{NASD}} P_{t-1}^{\mathrm{NASD}}\right) + \sum_{\mathrm{t-1}}^{\mathrm{p}} \lambda_i \, \Delta P_{t-1}^{\mathrm{SSE}} + \sum_{\mathrm{t-1}}^{\mathrm{p}} \phi_i \, \Delta P_{t-1}^{\mathrm{LSE}} + \sum_{\mathrm{t-1}}^{\mathrm{p}} \kappa_i \, \Delta P_{t-1}^{\mathrm{NASD}} + \varepsilon_{\mathrm{t}}^{\mathrm{SSE}} \qquad (6)$$

[9] It should be noted that the lags on the differenced terms in equation 5 are not specified by the theorem. Moreover, it is possible to include more than two differenced terms in the equation.

5 Data Analysis

In this chapter, the results of the statistical tests are presented and analysed.

The final results of the study are obtained from the Error Correction Model, ECM, presented in section 5.5. To get there, a number of tests have to be performed to make sure that the data is valid and qualifies for the final ECM test. These tests all contribute to the final results.[10]

5.1 Regression Analysis

Regression analysis was performed to make sure that the large sample of data was valid and significant. The data was imported from Microsoft Excel to Eviews and regressions were run on each of the separate stocks when all the data for one stock from the different stock exchanges were grouped together. Stockholm is the dependent variable in all regressions, since it is the home stock exchange of these companies.

Table 2. Statistical significance for price series

	Electrolux		Ericsson		Volvo	
	London	**Nasdaq**	**London**	**Nasdaq**	**London**	**Nasdaq**
R-square	0.96479	0.99420	0.96603	0.98661	0.95649	0.97931
Adj. R-square	0.96478	0.99420	0.96602	0.98660	0.95648	0.97930
Standard error	0.00281	0.00202	0.00278	0.00298	0.00323	0.00370
t-statistics	345.632	496.668	352.023	330.709	309.563	265.270

The t-statistics are all valid at the 99,5% level with 1 degree of freedom. The critical value for t with one degree of freedom is 6.313752 (95% level), 31.82052 (99% level) and 63.65674 (99,5% level).[11] Since this study has a very large sample, it can be argued that more degrees of freedoms should be used. However,

[10] Just small samples of the results of the tests are presented here for the sake of space. More of the test results can be found in the appendixes. The full results and the complete data are available upon request.

[11] The critical values can be found on The Statistical Homepage, http://www.statsoft.com/textbook/stathome.html, May 19, 2004.

the t-values for all three companies are very high and they are therefore almost independent of the number of degrees of freedom used. Furthermore, the r-square and adjusted r-square are 96% at the lowest, which means that 96% of the regression relation can be explained.

5.2 Schwarz Information Criterion

The Schwarz Information Criterion (SIC) was used to test for the appropriate number of lags. The SIC is a good criterion to use when the sample is large, as it is in this study (Enders, 2004). The SIC is supposed to be as small as possible. Some observations are lost when estimating a model using lagged variables. To start with, 12 lags were used, which means one observation per hour with 5-minute intervals. Thereafter, different lags, with one lag as the least, were used, in order to find out where the SIC was the smallest. The optimal lag length is presented in the table below.

Table 3. Lags

# LAGS	Stockholm	London	Nasdaq
Electrolux	1	4	5
Ericsson	1	5	1
Volvo	8	1	6

5.3 Unit Root test: Augmented Dickey-Fuller

The next step in the process of creating our Error Correction Model, is to test all price series for a unit root and to establish that the price series separately are non-stationary and integrated of order I (0). This is tested by an augmented Dickey-Fuller test. The ADF tests the unit root as the null hypothesis, for more details see 4.2.2. Table 4 is a summary of the statistical significance of the ADF. Furthermore, table 5 shows a summary of the ADF test for price series of each stock on each market. For more detailed results on the ADF test, see Appendix 4.

Table 4. Statistical significance for ADF

	Electrolux			**Ericsson**			**Volvo**		
	SSE	**LSE**	**NASD**	**SSE**	**LSE**	**NASD**	**SSE**	**LSE**	**NASD**
SIC	-0.03	3.41	-0.30	-4.03	-2.16	-4.55	4.157	0.399	3.509
Adj. R-square	0.435	0.787	0.465	0.479	0.794	0.418	0.794	0.519	0.786
Standard error	0.237	1.327	0.205	0.032	0.082	0.024	1.925	0.294	1.378
Prob. (F- stat.)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

As shown in table 4, all price series are statistically significant. For example, the standard error is very small for almost all of the price series. In the case of the price series for Volvo at SSE, where the standard error is the highest among all series, the adjusted R-square is high. Moreover, the probability of the F-test shows 100% significance for all the price series.

Table 5. ADF test statistics

	Stockholm	**London**	**Nasdaq**
Electrolux	-30.29	-12.09	-17.17
Ericsson	-31.34	-32.44	-17.96
Volvo	-50.39	-29.50	-21.97

MacKinnon critical values:
1% -3.43
5% -2.86
10% -2.56

As shown in table 5, when using MacKinnon critical values, all the price series can reject the null hypothesis at 99 percent level. Thus, it is statistically significant at 99 percent level that all price series in this study has a unit root and that no cointegration exist. Moreover, since the null hypothesis can be rejected, the result of the ADF test prove that all the price series are I (0). Furthermore, with this result, the econometric tests to create an Error Correction Model can now be continued by performing the Johansen Maximum Likelihood Procedure.

5.4 Johansen ML Procedure

5.4.1 Statistical significance

The null hypothesis for the statistic λ_{trace} (r) test, is that the number of cointegrating vectors is less than or equal to r. Moreover, the null hypothesis for the statistic λ_{max} (r, r+1) test, is that the number of cointegrating vectors is r against the alternative of r+1 cointegrating vectors. (Johansen 1988)

The number of lags used in the Johansen test is tested by Schwarz information criterion, see table 3 in 5.2.

Table 6. Johansen: Electrolux

Series: ELUX_STHLM ELUX_LONDON ELUX_NASDAQ
Lags interval (in first differences): 1 to 5

Unrestricted Cointegration Rank Test

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	5 Percent Critical Value	1 Percent Critical Value
None **	0.140130	**144.5475**	34.91	**41.07**
At most 1	0.006148	6.859051	19.96	24.60
At most 2	0.001353	1.234942	9.24	12.97

*(**) denotes rejection of the hypothesis at the 5%(1%) level
Trace test indicates 1 cointegrating equation(s) at both 5% and 1% levels

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	5 Percent Critical Value	1 Percent Critical Value
None **	0.140130	**137.6884**	22.00	**26.81**
At most 1	0.006148	5.624109	15.67	20.20
At most 2	0.001353	1.234942	9.24	12.97

*(**) denotes rejection of the hypothesis at the 5%(1%) level

Max-eigenvalue test indicates 1 cointegrating equation(s) at both 5% and 1% levels

The trace test for Electrolux, where r = 0, is 144.55, which is greater than the 99 percent level critical value of 41.07. Therefore, the null hypothesis can be rejected at the 99 percent level of statistical significance, and thus one cointegration vector exists.

The max-eigen test for Electrolux, where r = 1, is 137.69, which is greater than the 99 percent level critical value of 26.81. Therefore, the null hypothesis can be rejected at the 99 percent level of statistical significance, and thus one cointegration vector exists. In conclusion, there is a single cointegrating vector for Electrolux, that is significant at the 99 percent level both for the trace- and max-eigen test.

Table 7. Johansen: Ericsson

Series: ERIK_STHLM ERIK_LONDON ERIK_NASDAQ
Lags interval (in first differences): 1 to 5

Unrestricted Cointegration Rank Test

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	5 Percent Critical Value	1 Percent Critical Value
None **	0.059537	**83.91394**	34.91	**41.07**
At most 1 **	0.020919	**28.05571**	19.96	**24.60**
At most 2	0.009642	8.817234	9.24	12.97

*(**) denotes rejection of the hypothesis at the 5%(1%) level
Trace test indicates 2 cointegrating equation(s) at both 5% and 1% levels

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	5 Percent Critical Value	1 Percent Critical Value
None **	0.059537	**55.85823**	22.00	**26.81**
At most 1 *	0.020919	19.23848	15.67	20.20
At most 2	0.009642	8.817234	9.24	12.97

*(**) denotes rejection of the hypothesis at the 5%(1%) level
Max-eigenvalue test indicates 2 cointegrating equation(s) at the 5% level
Max-eigenvalue test indicates 1 cointegrating equation(s) at the 1% level

The trace test for Ericsson, where r = 0, is 83.91, which is greater than the 99 percent level critical value of 41.07. Therefore, the null hypothesis can be rejected at the 99 percent level of statistical significance, and thus one cointegration vector exists. Moreover, the trace test for two cointegrating vectors is 28.06, which is greater than the 99 percent level critical value of 24.60. This means that two cointegrating vectors exist for Ericsson at the 99 percent level for the trace test.

The max-eigen test for Ericsson, where r = 1, is 55.86, which is greater than the 99 percent level critical value of 26.81. Therefore, the null hypothesis can be rejected at the 99 percent level of statistical significance, and thus one cointegration vector exists. In conclusion, there are two cointegrating vectors for Electrolux, that are significant at the 99 percent level for the trace test, but only one for the max-eigen test. In our Error Correction Model, we choose to follow the max-eigen test and include one cointegrating vector for Ericsson.

Table 8. Johansen: Volvo

Series: VOLVO_STHLM VOLVO_LONDON VOLVO_NASDAQ
Lags interval (in first differences): 1 to 8

Unrestricted Cointegration Rank Test

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	5 Percent Critical Value	1 Percent Critical Value
None **	0.134955	**117.3516**	34.91	**41.07**
At most 1	0.006603	6.012147	19.96	24.60
At most 2	0.001203	0.924110	9.24	12.97

*(**) denotes rejection of the hypothesis at the 5%(1%) level
Trace test indicates 1 cointegrating equation(s) at both 5% and 1% levels

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	5 Percent Critical Value	1 Percent Critical Value
None **	0.134955	**111.3394**	22.00	**26.81**
At most 1	0.006603	5.088037	15.67	20.20
At most 2	0.001203	0.924110	9.24	12.97

*(**) denotes rejection of the hypothesis at the 5%(1%) level
Max-eigenvalue test indicates 1 cointegrating equation(s) at both 5% and 1% levels

The trace test for Volvo, where r = 0, is 117.35, which is greater than the 99 percent level critical value of 41.07. Therefore, the null hypothesis can be rejected at the 99 percent level of statistical significance, and thus one cointegration vector exists.

The max-eigen test for Volvo, where r = 1, is 111.34, which is greater than the 99 percent level critical value of 26.81 Therefore, the null hypothesis can be rejected at the 99 percent level of statistical significance, and thus one cointegration vector exists. In conclusion, there is a single cointegrating vector for Volvo, that is significant at the 99 percent level both for the trace- and max-eigen test.

5.4.2 Cointegration vectors

Table 9. Cointegration vectors, β

	Electrolux			**Ericsson**			**Volvo**		
SSE	1	8,032	-0,886	1	-3,138	-1,468	1	59,695	-0,98
LSE	0,125	1	-0,11	-0,319	1	0,468	0,017	1	-0,016
NASD	-1,129	-9,065	1	-0,681	2,138	1	-1,021	-60,932	1
∑	-0,004	-0,033	0,004	0	0	0	-0,004	-0,237	0,004

In table 9, the cointegration vectors, β, are normalized, which means that the dependant variable equals one, to see how the other variables is affected by the dependant variable (see Appendix 5 for a sample of the test results). As explained in 4.2.6, β is the matrix of the cointegrating parameters, and in Johansen's cointegration test, the null hypothesis is that there is no cointegration. Table 9 (∑ row) shows that a rejection of the null hypothesis can be made and a long run relationship exists between the price series of all the three stocks on the three stock exchanges. Moreover, since all the β's are equal or close to zero, it is statistically significant for all three stocks, that the price series are stationary and cointegrated.

An assumption is made, that the normalized values of the cointegrating vectors of each stock on each stock exchange equals or is close to zero (see ∑ row). The reason for this is that when β is close to zero, the prices of the stocks move close together on the different exchanges. Accordingly, table 9 shows that all prices for all stocks on all exchanges move close together. For example, when a change in the price of the Ericsson share occurs on SSE (SSE dependent and equals 1), the other exchanges correct their prices almost instantly (the ∑ in table 9 is 0). This means that for the price of an Ericsson share, SSE, London and Nasdaq are cointegrated. For Volvo and Electrolux, the price adjustment mechanism takes slightly longer than for Ericsson. The first conclusion from this result, is that prices on SSE, LSE and NASD are cointegrated and mutually adjusting.

Another assumption, which was made in the methodology, stated that, if cointegration does not exist, this would mean that markets would not be efficient and there would be arbitrage opportunities. Thus, the prices of a stock does not necessarily have to be equal at every point in time on two or more exchanges, since the arbitrary opportunity has to cover transaction costs. Furthermore, a consideration of exchange rate risk and the time difference have to be included in the arbitrary opportunity. It is not likely that the prices would differ to the extent that the arbitrage spread would cover both transaction costs and exchange rate risk. Moreover, since this study is based on ex-post observations and the cointegration vectors in table 9 show that the markets quickly adjust their quotes, the conclusion that there does not exist any arbitrary opportunities can be drawn.

Evidence from the Johansen ML procedure show that prices on SSE, LSE and NASD are cointegrated, and thus a long-run equilibrium relationship exists. This relationship is presented in equation 7, which is the cointegration equation of this study. It can be interpreted as a long-run equilibrium relationship between the variables.

$$\Delta P_{\mathrm{t}}^{\mathrm{STO}} = \mathrm{a}_{0}^{\mathrm{STO}} + \alpha^{STO} \left(P_{t-1}^{STO} + \beta^{\mathrm{LON}} P_{t-1}^{LON} + \beta^{\mathrm{NASD}} P_{t-1}^{\mathrm{NASD}} \right) \qquad (7)$$

5.5 Error Correction Model, ECM

As mentioned earlier, the final test of this study is an Error Correction Model. The ECM in this study is a Vector Error Correction, VEC. The outcome of this test, or rather the interpretation of the alpha (α) coefficients, tells where (on what stock exchange) price discovery takes place and to what extent prices on one stock exchange respond to prices on another stock exchange. Before performing the VEC, the equations were written. The equations are the following:

5.5.1 ECM Stockholm, SSE

$$\Delta P_{\mathrm{t}}^{\mathrm{SSE}} = \mathrm{a}_0^{\mathrm{SSE}} + \alpha^{SSE}\left(P_{t-1}^{SSE} + \beta^{\mathrm{LSE}} P_{t-1}^{LSE} + \beta^{\mathrm{NASD}} P_{t-1}^{NASD}\right) + \sum_{\mathrm{t-1}}^{\mathrm{p}} \lambda_i \,\Delta P_{t-1}^{SSE} + \sum_{\mathrm{t-1}}^{\mathrm{p}} \phi_i \,\Delta P_{t-1}^{LSE} + \sum_{\mathrm{t-1}}^{\mathrm{p}} \kappa_i \,\Delta P_{t-1}^{NASD} + \varepsilon_{\mathrm{t}}^{\mathrm{SSE}}$$

5.5.2 ECM London, LSE

$$\Delta P_{\mathrm{t}}^{\mathrm{LSE}} = \mathrm{a}_0^{\mathrm{LSE}} + \alpha^{LSE}\left(P_{t-1}^{LSE} + \beta^{\mathrm{SSE}} P_{t-1}^{SSE} + \beta^{\mathrm{NASD}} P_{t-1}^{NASD}\right) + \sum_{\mathrm{t-1}}^{\mathrm{p}} \phi_i \,\Delta P_{t-1}^{LSE} + \sum_{\mathrm{t-1}}^{\mathrm{p}} \lambda_i \,\Delta P_{t-1}^{SSE} + \sum_{\mathrm{t-1}}^{\mathrm{p}} \kappa_i \,\Delta P_{t-1}^{NASD} + \varepsilon_{\mathrm{t}}^{\mathrm{LSE}}$$

5.5.3 ECM Nasdaq, NASD

$$\Delta P_{\mathrm{t}}^{\mathrm{NASD}} = \mathrm{a}_0^{\mathrm{NASD}} + \alpha^{NASD}\left(P_{t-1}^{NASD} + \beta^{\mathrm{SSE}} P_{t-1}^{SSE} + \beta^{\mathrm{LSE}} P_{t-1}^{LSE}\right) + \sum_{\mathrm{t-1}}^{\mathrm{p}} \kappa_i \,\Delta P_{t-1}^{NASD} + \sum_{\mathrm{t-1}}^{\mathrm{p}} \lambda_i \,\Delta P_{t-1}^{SSE} + \sum_{\mathrm{t-1}}^{\mathrm{p}} \phi_i \,\Delta P_{t-1}^{LSE} + \varepsilon_{\mathrm{t}}^{\mathrm{NASD}}$$

where:

$\Delta P_{\mathrm{t}}^{\mathrm{NAS}}$ is the change in price on the stock exchange at time t

$\mathrm{a}_0^{\mathrm{NASD}}$ is a constant (intercept)

α^{NASD} is the slope (regression coefficient), speed of adjustment parameter

β^{STO} *is the cointegration equation value obtained in the Johansen test (see 6.4)*

P is the number of lags

ε_t^{NASD} *is a residual (error term)*

5.5.4 Alpha Coefficient

The coefficients of main interest to this study are the alphas (α), since *"the estimates of alphas indicate the extent to which the price series respond to a deviation from the equilibrium relationship"* (Eun and Sabherwal, p. 562). The alpha coefficient estimates are presented in table 13. First, a presentation of the statistics from the VEC tests is presented to show that they are statistically significant.

Table 10. Statistical significance for VEC: Electrolux

	SSE	LSE	NASD
R-squared	0.064534	0.493400	0.147174
Adj. R-squared	0.048874	0.484919	0.132897
S.E. equation	0.195504	2.747870	0.188486
F-statistic	4.120774	58.17702	10.30829
Akaike AIC	-0.409082	4.876917	-0.482202
Schwarz SC	-0.324597	4.961402	-0.397717
Mean dependent	-0.015488	-0.016818	-0.017104
S.D. dependent	0.200464	3.828764	0.202415

Table 11. Statistical significance for VEC: Ericsson

	SSE	LSE	NASD
R-squared	0.067471	0.104873	0.206660
Adj. R-squared	0.051825	0.089854	0.193349
S.E. equation	0.030566	0.041571	0.024618
F-statistic	4.312250	6.982722	15.52543
Akaike AIC	-4.120434	-3.505418	-4.553259
Schwarz SC	-4.035802	-3.420786	-4.468627
Mean dependent	-0.002610	-0.002570	-0.002234
S.D. dependent	0.031390	0.043574	0.027410

Table 12. Statistical significance for VEC: Volvo

	SSE	LSE	NASD
R-squared	0.066504	0.089434	0.481006
Adj. R-squared	0.036350	0.060021	0.464242
S.E. equation	0.233070	0.297282	1.087319
F-statistic	2.205512	3.040659	28.69236
Akaike AIC	-0.042947	0.443741	3.037318
Schwarz SC	0.108218	0.594906	3.188483
Mean dependent	-0.004232	-0.002977	-0.006475
S.D. dependent	0.237425	0.306627	1.485500

As shown in the tables above, the SIC is low for all the VEC models. Moreover, the F-statistics for all three VEC models are statistically significant at the 1% level, where the critical value is 2.18 for a sample over 100 (Andersson et al). Now the coefficients of main interest to this study, the alphas, will be considered.

Table 13. Alpha Coefficient Estimates from VEC

α	Electrolux			Ericsson			Volvo		
	SSE=1	LSE=1	NASD=1	SSE=1	LSE=1	NASD=1	SSE=1	LSE=1	NASD=1
SSE	-0,037	-0,005	0,041	-0,038	0,012	0,026	0,037	0,0006	-0,038
LSE	0,061	0,008	-0,069	0,063	-0,02	-0,043	0,042	0,0007	-0,043
NASD	0,18	0,022	-0,204	0,108	-0,034	-0,074	0,792	0,013	-0,804
∑Δ	0,204	0,025	-0,232	0,133	-0,042	-0,091	0,871	0,0143	-0,885

Presented in the table above are the estimates for the coefficients of main interest to this study, the alphas (α). Now these values will be reflected and commented upon.

If the prices on SSE (P^{SSE}_{t-1}) are larger than prices on LSE (P^{LSE}_{t-1}), one way to reduce that gap is that, at time t, P^{SSE} declines and P^{LSE} increases. Then α^{SSE} should be negative and α^{LSE} should be positive to reach equilibrium.

According to H_1 price discovery takes place on the home stock exchange, SSE. If this is true, then consequently we should expect SSE to spur LSE and Nasdaq and they should respond to deviations from the home stock exchange. Then α^{SSE} should be negative and α^{LSE} should be positive in a SSE/LSE example.

The above assumptions are the same as Eun and Sabherwal (2003) make in their study, where they expect the alpha coefficient for their home stock exchange Toronto (α^{TSE}) to be negative and the alphas for their other stock exchange, American, (combined as α^{US}) to be positive. In their case, the coefficients have the expected signs. A reminder is that this study has three variables compared to Eun and Sabherwal's two. This means that they compare two stock exchanges and can state which exchange respond to which. For 58 of their 62 stocks, Canadian prices respond to deviations from U.S. prices. In our case, since a third variable is included, the outcome of which exchange that responds to which prices can vary among our three variables.

For Ericsson, the alphas are –0,038 (α^{SSE}) for SSE and 0,063 (α^{LSE}) for LSE. So if P^{SSE} is greater than P^{LSE} by 1%, then price adjustments should take place so that after 1 lag, which is 5 minutes, P^{SSE} would decline by 0,038 % and P^{LSE} increases by 0,063%. This means that SSE would spur the stock price of Ericsson on LSE. Moreover, LSE would respond to price divergence on SSE.

Before further comments are made on the alpha values, the structure of trade on the different stock exchanges should be considered.

Table 14. Structure of traded shares

% of shares traded 2003	SSE	LSE	NASD	Total shares traded 2003
Electrolux	78,5%	21%	0,5%	611 million
Ericsson	74,5%	12,6%	12,8%	69 *billion*
Volvo	80,5%	17,6%	1,9%	542 million

As the table of above shows, all three companies have a majority of their shares traded on their home stock exchange. Furthermore, for Electrolux and Volvo, LSE is the second largest place for trade while Ericsson trade slightly more on Nasdaq than on London. Finally, Ericsson has the significantly largest portion of trade of their stock on Nasdaq of these three companies.

The alpha coefficient estimates in table 13 are now reconsidered, one can see that the first column of each company (read vertically), where SSE is equal to one, is the most important scenario, since a majority of the trade of the stocks takes place on this exchange. For Electrolux and Volvo, the second column of each company respectively, where LSE equals one, is the second most important scenario to consider. For Ericsson it is instead the alphas where Nasdaq equals one that is the second most important, but the column where London equals one is almost as important.

For **Electrolux**, the alphas for SSE are –0,037 (α^{SSE}) and 0,061 (α^{LSE}) for LSE. So, if P^{SSE} is greater than P^{LSE} by 1%, then price adjustments will take place so that after 1 lag (5 minuets) P^{SSE} will decline by 0,037 % and P^{LSE} will increases by 0,061%. This means that SSE would spur the stock price of Electrolux on LSE and that LSE would respond to price divergence on SSE. Furthermore, if P^{SSE} is greater than P^{NASD} by 1%, P^{SSE} should still decrease by 0,037 % while P^{NASD} should respond by increasing 0,18%. In both of these scenarios the price on SSE decline by 0,037 % of the divergence in 5 minutes. Moreover, since SSE is the dependent variable and the alpha is the speed adjustment parameter Nasdaq respond faster to price difference on SSE than LSE does. In conclusion, in the above example SSE spurs the stock price on both exchanges. This means that price discovery takes place on SSE, since SSE is the stock exchange that drives the price and makes LSE and Nasdaq respond to try to eliminate the price divergence on SSE.

A second likely, but less likely than the first, scenario is that prices on SSE and NASD respond to prices in London. If $P^{LSE} > P^{SSE}$ by 1%, then the expected price adjustments after 1 lag should take place so that P^{LSE} declines and P^{SSE} increases. This is not the case. P^{LSE} actually *increases* by 0,008% while as P^{SSE} decreases by 0,005%. Both stock exchanges adjust "in the wrong direction". This means that prices on SSE does not respond to prices on LSE, which is further evidence of that price discovery takes place on SSE for Electrolux.

Next, consider $P^{LSE} > P^{NASD}$ by 1%, P^{LSE} still *increase* by 0,008% and P^{NASD} increase by 0,022% as it should when trying to reduce the price gap. Nasdaq respond fast to the divergence and are trying to catch up with LSE and since the adjustment on Nasdaq (0,022%) is larger than the increase on LSE the price divergence will eventually disappear. In conclusion, Nasdaq responds to a change on LSE, but LSE are trying to increase the price gap, which will fail in the long run.

The third scenario, consider $P^{NASD} > P^{SSE}$ by 1%, then after 5 minutes P^{NASD} has decreased by 0,204% and P^{SSE} increased by 0,041% as it should when trying to reduce the price gap. In this case both exchanges respond in the expected direction, but a main point to note is that Nasdaq has a large and a fast respond. Hence, Nasdaq is trying to eliminate its own price divergence against SSE. So even if SSE respond to a price divergence, Nasdaq respond both larger and faster after 5 minutes, in conclusion Nasdaq does not spur prices on SSE. Furthermore, consider $P^{NASD} > P^{LSE}$ by 1%, then after 5 minutes P^{NASD} has decreased by 0,204% but P^{LSE} also *decrease* by 0,069%, hence LSE moves in the wrong direction when trying to reduce the price gap. Since Nasdaq has a larger respond to its own price divergence than LSE, the equilibrium price will be reached. Moreover, this means that prices on LSE does not respond to price divergence on Nasdaq, which is evidence that price discovery does not take place on Nasdaq for Electrolux since Nasdaq does not spur prices neither on LSE or SSE.

After having considered the above scenarios a conclusion can be made that the price discovery for Electrolux takes place on the home market SSE, which means that H_1 can be accepted for Electrolux. This conclusion might not be so surprising since 78,5% of the Electrolux share is traded on SSE (for company figures see appendix 1). On the other hand it is surprising that only a small portion of the

Electrolux share is traded on Nasdaq and that Nasdaq does not contribute to price discovery. This since if a comparison is made between Sweden and the USA only we can see that only 3,5% of the total sale are in Sweden and compared to 35,8 % in the USA. Moreover, Electrolux only has 9% of total staff in Sweden compared to 26% in the USA and Electrolux is considered to be one of Whirpool's worst competitors. Even though the above figures indicate that Nasdaq should be an important stock exchange for Electrolux since the USA is an important market, this is not the case. SSE contributes alone to the price discovery of Electrolux whereas Nasdaq responds fast to divergence in price on SSE and is trying to catch up.

For **Ericsson**, the alphas are –0,038 (α^{SSE}) for Stockholm and 0,063 (α^{LSE}) for London when SSE is the dependent variable. So if P^{SSE} is greater than P^{LSE} by 1%, then price adjustments after 1 lag (5 minuets) should take place so that P^{SSE} decline by 0,038 % and P^{LSE} increases by 0,063%. This means that LSE respond to a price divergence on SSE and that SSE spur the stock price on LSE. This indicates that price discovery takes place on SSE. With the same line of reasoning, if P^{SSE} is greater than P^{NASD} by 1%, consequently, P^{SSE} will still decrease by 0,038 % while P^{NASD} will increase by 0,108% in 5 minutes. This is a fast and large respond of Nasdaq to a price divergence on SSE. As in the case of Electrolux, Nasdaq responds faster and larger after 1 lag to a price divergence on SSE than LSE does. In both cases Nasdaq is the follower and is trying to catch up as fast as possible to price divergence on SSE.

The second scenario for Ericsson is that prices on SSE and LSE respond to prices on Nasdaq. If P^{NASD} is larger than P^{SSE} by 1%, price adjustments after 1 lag should take place so that P^{NASD} declines by 0,074% and P^{SSE} increases by 0,026%. In this case SSE respond to a price divergence on Nasdaq, but Nasdaq respond larger than SSE and is trying to eliminate the divergence it self. So, if a price change takes place on Nasdaq, Nasdaq does not spur SSE, instead it is trying to eliminate the price difference. A conclusion can be made that Nasdaq does not contribute to price discovery, since it rather is trying to eliminate the price divergence than spur SSE. With the same line of reasoning as above, if P^{NASD} is larger than P^{LSE} by 1%, P^{NASD} will still decrease by 0,074%. One would expect P^{LSE} to be positive, but it will actually also *decline*, with 0,043%. One possible explanation is that the stock price of Ericsson on LSE does not respond to price divergence on Nasdaq. Instead of responding LSE is trying to increase the price difference of the Ericsson stock. This will not succeed in the long run since the respond is faster and larger on Nasdaq than on LSE (0,074% compared to 0,043%) and will eliminate the price gap back to equilibrium. This is in line with the assumption that there does not exist an arbitrary opportunity. Moreover, an assumption is made that the transaction cost is higher than the price gap, which would not allow an arbitrage opportunity, and therefore a price gap can exist in the short term. In conclusion, Nasdaq does not spur the price on LSE; hence price discovery of the Ericsson stock does not take place on Nasdaq.

The third scenario for Ericsson is that prices on SSE and Nasdaq respond to prices on the LSE. If $P^{LSE} > P^{SSE}$ by 1%, then P^{LSE} will decrease by 0,02% while P^{SSE} will increase by 0,012%. Like the second scenario SSE respond to a price divergence on LSE, but just like Nasdaq LSE respond larger and is trying to eliminate the price gap it self. Hence, LSE does not spur prices on SSE. Furthermore, if $P^{LSE} > P^{NASD}$ by 1%, then P^{LSE} will still decrease by 0,02%. In this case you would expect P^{NASD} to be positive, but it is negative and *decreases* by 0,034%. This will make the price gap even larger. Like stated above the prices on the LSE might not respond to price divergence on Nasdaq. In this case it is found that prices on Nasdaq might not respond to prices on the LSE, so it is rather safe to assume that prices of the Ericsson stock on these two stock exchanges does not respond to each other. Which leads to that neither LSE nor Nasdaq contributes to price discovery of the Ericsson stock. None of these are the home stock exchange for Ericsson and together they trade less than half of the volume traded on the SSE. As for H_1 evidence suggests that price discovery for Ericsson takes place only on the home stock exchange SSE. Thus, H_1 can be accepted for Ericsson. This is not surprising since Ericsson is the most traded stock on the SSE, of the 69 *billion* Ericsson shares that was traded in 2003, about 74,5 percent were traded on SSE. Ericsson has the significant highest trading volume on SSE of all the listed companies, which makes Ericsson important to SSE and this might contribute to that price discovery of Ericsson takes place on SSE.

For **Volvo**, the alphas for are 0,037 (α^{SSE}) for SSE and 0,042 (α^{LSE}) for LSE after 1 lag when SSE is the dependent variable. . This means that if P^{SSE} is greater than P^{LSE} by 1%, then P^{SSE} will actually *increase* the price gap even more with 0,037%. P^{LSE} will then increase to try to reduce the gap by 0,063%. This will lead to that prices on SSE are higher than on LSE in the short term, but since the respond to the price deviations are larger on LSE the price gap will eventually disappear and reach equilibrium. There is a sign here that SSE spur prices on LSE, since LSE respond and are trying to catch up, which could lead to that price discovery take place on SSE. Next, consider when P^{SSE} is greater than P^{NASD} by 1%. P^{SSE} will still *increase* by 0,037% and increase the price gap in the short run. P^{NASD} will increase by 0,792% to try to reduce the original gap of 1%. The respond of Nasdaq to the price divergence on SSE is very large. In 5 minutes Nasdaq change with 0,792% compared to 0,037% on SSE this leads to that the price deviation will be eliminated fast. Evidence here suggest that SSE spur prices on Nasdaq, even though SSE is trying to increase the price gap Nasdaq is working hard and fast to catch up with SSE, hence SSE is driving stock exchange and Nasdaq is the follower.

These two scenarios suggest that the price of a Volvo share is generally higher in the short run on SSE than on LSE and Nasdaq. The price gap between SSE and Nasdaq will be eliminated rather fast, while it will take slightly longer time for LSE to adjust. According to discussion in 5.4.2, there should not be any arbitrary opportunities even if a price gap exists in the short run. This since, for a arbitrary opportunity to exist the arbitrary spread have to cover both transaction cost and exchange rate risks. Nevertheless, it is an interesting fact that SSE is trying to increase the price divergence to the other two stock exchanges. Moreover, over 80% of the total trade of the stock take place on SSE and in both the above examples SSE spur prices on LSE and Nasdaq, hence an indication that the price discovery for Volvo take place on the home stock exchange SSE.

The second scenario, if $P^{LSE} > P^{SSE}$ by 1%, P^{LSE} will increase by 0,0007%, which increases the price gap. P^{SSE} will increase by 0,0006% to try to reduce the gap. Even though SSE responds to the price deviation on LSE, LSE respond slightly more to its own price deviation. So, no statement can be made that LSE spur SSE, instead the two exchanges respond almost the same and the response to the price deviation is very small after the first 5 minutes. Then, if $P^{LSE} > P^{NASD}$ by 1%, P^{LSE} will still increase by 0,0007% while P^{NASD} will increase by 0,013% to try to reduce the gap. In this case Nasdaq respond to price divergence on LSE, which indicates that LSE spur prices on Nasdaq for Volvo. Once again the prices adjustment on Nasdaq is fast, which states that Nasdaq is the follower and is working hard to catch up to price divergences on the LSE.

The third scenario, consider $P^{NASD} > P^{SSE}$ by 1%, then after 5 minutes P^{NASD} has decreased by 0,804% and P^{SSE} has also *decreased* by 0,038%. In this case SSE does not respond to the price divergence. Nasdaq on the other hand responds very large to its own price gap and is trying to eliminate it fast. This is further evidence that SSE does not respond to Nasdaq while SSE spur prices on Nasdaq. Furthermore, consider $P^{NASD} > P^{LSE}$ by 1%, then after 5 minutes P^{NASD} has decreased by 0,804% and P^{LSE} also has *decrease* by 0,043%, hence LSE moves in the wrong direction when trying to reduce the price gap. Moreover, this means that prices on LSE does not respond to price divergence on Nasdaq, which is evidence that price discovery does not take place on Nasdaq for Volvo since Nasdaq does not spur prices neither on LSE or SSE.

After having considered the above three scenarios a conclusion can be made that the price discovery for Volvo mainly takes place on the home market SSE. An acceptation of H_1 can be made, since SSE spur prices on LSE and Nasdaq when the change takes place on SSE. Moreover, SSE does not respond to a change on Nasdaq and the respond to a change on LSE is very small.

There is evidence in the analysis that Nasdaq does not contribute to price discovery at all for any of the three stocks. Nasdaq is the follower, which respond fast to a price divergence on the other two stock exchanges. This is shown in table 13, where the alpha coefficients for Nasdaq contribute the most to the total adjustments for each stock ($\sum\alpha$). Especially when responding to prices in Stockholm, prices on Nasdaq responds faster than prices on LSE for all three stocks.

Now to the H_2 hypothesis, which state: To the extent to which the London Stock Exchange contributes to the price discovery of the Swedish stocks is greater than the extent to which Nasdaq contributes to the price discovery of the same stocks. This hypothesis can be accepted for all the stocks since in all cases LSE does not respond to a price divergence on Nasdaq. Further, LSE spur prices on Nasdaq, which respond to a price change on LSE and is trying to eliminate the price gap.

The main finding of this study is that H_1 hypothesis can be accepted for all three stocks. SSE spurs the prices on both LSE and Nasdaq. Moreover, SSE does not respond or only slightly respond to price divergences on LSE and Nasdaq for all three stocks. This finding might not be so surprising since Stockholm is the home stock exchange for the Swedish companies, and a majority of the trade takes place on SSE. Moreover, this result might have been different if a company like AstraZeneca had been included. They are partially Swedish and British, and have substantial trade on exchanges in both of these countries. Since only Swedish companies were included in this study, this reasoning is left for future research.

The result of this study can be compared to the studies it replicates. For the Canadian study of Eun and Sabherwal (2003), evidence states that both Toronto and their combined U.S. stock exchange contribute to price discovery. This is not the case for this study, where the price discovery takes place on the home stock exchange SSE. In the case of Ericsson SSE does respond to a price divergence on LSE, but LSE react even more itself tying to reduce the price gap.

It can be noted that LSE contribute more to price discovery than Nasdaq. The total trade for Volvo and Electrolux is much less on Nasdaq than on LSE and SSE. With this in mind, it might not be surprising that Nasdaq follows price divergence on SSE and some on LSE. A possible explanation of the fast reaction to price divergences on SSE for Nasdaq compared to LSE might be that Nasdaq is an OTC market and LSE an auction market. An assumption is that a computerised OTC market might be slightly more efficient than the “human factored” auction markets. It would be interesting to test price discovery with emphasis on the efficiency of OTC and auction markets respectively. We leave this for future research.

In the German study of Grammig, Melvin and Schlag (2000), evidence suggests that a large portion of price discovery take place on the home stock exchange, Frankfurt, which the H_1 of this study is based on. This hypothesis is accepted since evidence shows that SSE contributes to the price discovery for all the three stocks.

6 Conclusions

This final chapter contains the conclusions that have be drawn from the results presented in chapter five. They are further compared to the conclusions of previous studies.

In this study we have examined three stocks that are listed on three stock exchanges. The first conclusion that can be made from this study is that prices on SSE, LSE and NASD are cointegrated and mutually adjusting. Therefore, there exist a long-run equilibrium relationship.

Moreover, the second conclusion is that the cointegration vectors from the Johansen test show that the markets quickly adjust their quotes and that no arbitrary opportunities exist. This conclusion is supported by the fact that the price for a Volvo stock is higher in general in the short run on SSE where over 80% of the total trade of the stock take place. An assumption can be made that there does not exist and arbitrary opportunities due to that the spread does not cover the transaction cost and exchange rate risks and this deviation only exist for a short period of time before LSE and Nasdaq eliminates the price gap.

The main finding of this study is that H_1 hypothesis can be accepted for all three stocks. SSE spurs the prices on both LSE and Nasdaq. Moreover, SSE does not respond or only slightly respond to price divergences on LSE and Nasdaq for all three stocks. This finding might not be so surprising since Stockholm is the home stock exchange for the Swedish companies, and a majority of the trade takes place on SSE. Moreover, the second hypothesis H_2 can also be accepted, this since in all cases LSE does not respond to a price divergence on Nasdaq. Further, LSE spur prices on Nasdaq, which respond to a price change on LSE and is trying to eliminate the price gap

One of our main findings is that Nasdaq responds fast to price divergences both on LSE and SSE. One explanation could be that Nasdaq is one the most liquid stock exchange in the world. Another possible explanation could be that, regarding sales turnover, the market in the U.S. is more important for all three companies than the UK market. This might lead to than investors on Nasdaq keep a closer eye to price deviations on SSE and LSE. A third possible explanation is that Nasdaq is an OTC market, while SSE and LSE are auction markets. An assumption is that a computerized OTC market might be slightly more efficient than the “human factored” auction markets. It would be interesting to test price discovery with emphasis on the efficiency of OTC and auction markets respectively. We leave this for future research.

To summarize, in the table below a comparison of studies is presented to give an insight of how this study is positioned toward previous research and how it contributes to science.

Table 15. Summary and comparison of studies

	Canadian study	**German study**	**Our study**
Authors:	Eun, Sabherwal	Grammig, Melvin, Schlag	Bäckman, Hellberg, Jönsson
Published in:	Journal of Finance, 2003	(Working paper, 2000)	(Master Thesis, 2004)
Stock exchanges included:	Toronto Stock Exchange New York Stock Exchange Nasdaq American Stock Exchange	Frankfurt Stock Exchange New York Stock Exchange	Stockholm Stock Exchange London Stock Exchange Nasdaq
Firms included:	62 Canadian firms	3 German blue chip firms[12]	3 Swedish blue chip firms
Time period:	6 months (February-July 1998)	3 months (August-October 1999)	49 days (2003)
Intraday time interval:	10 minutes	5 minutes	5 minutes
Overlap trading time:	Perfect overlap	1,5/ 2 hour overlap	7,5/ 2,5 and 2 hour overlap
Share type:	Ordinary shares	ADRs & ordinary shares	ADRs & ordinary shares
Findings:	This study finds that prices on the TSE and US exchange are cointegrated and mutually adjusting. For 58 of the 62 firms, the Canadian prices respond to deviations from the U.S. prices. Both the TSE and the U.S. exchange contribute to price discovery.	The evidence of this study suggests that for most part the price discovery take place in the home market, in Frankfurt. The home market largely determines the random walk component of the international value of the companies. Thus, the result differs across the stocks. For example for one of the companies included in the study 20% of the price innovation is determined on NYSE.	The evidence of this study shows that prices on SSE, LSE and NASD are cointegrated and mutually adjusting. The evidence suggests that in all three cases price discovery take place on the home stock exchange SSE. Moreover, LSE contributes more to price discovery than Nasdaq.

[12] Blue chip firm: low risk shares in good companies

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Eviews 4.0 Users Help guide (feature in Eviews 4.0 software)

Appendixes

The full results and the data can be provided from the authors upon request. For the sake of space, only a small sample with examples from Electrolux is presented below.

Appendix 1. Company figures

2003 figures SEK million

% of total sales	Sweden	UK	US	Total sales
Electrolux	3.5%	5.3%	35.8%	124,077
Ericsson	5%	NA	14%	117,738
Volvo	NA	NA	24%	174,768

% of total staff	Sweden	UK	US	Total staff
Electrolux	9%	3%	26%	77,140
Ericsson	47%	NA	5%	51,583
Volvo	36%	NA	17%	71160

% of shares traded	SSE	LSE	NASD	Total shares
Electrolux	78.5%	21%	0.5%	324,1 million
Ericsson	74.5%	12.6%	12.8%	16,13 billion
Volvo	80.5%	17.6%	1.9%	441,5 million

Appendix 2. Regression results, Electrolux

Dependent Variable: ELUX_STHLM
Method: Least Squares
Date: 05/05/04 Time: 12:29
Sample(adjusted): 3 4699
Included observations: 4361
Excluded observations: 336 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
ELUX_LONDON	0.971405	0.002811	345.6329	0.0000
C	4.695660	0.459377	10.22181	0.0000

R-squared	0.964796	Mean dependent var	163.3123
Adjusted R-squared	0.964788	S.D. dependent var	7.234635
S.E. of regression	1.357571	Akaike info criterion	3.449730
Sum squared resid	8033.631	Schwarz criterion	3.452656
Log likelihood	-7520.135	F-statistic	119462.1
Durbin-Watson stat	1.603210	Prob(F-statistic)	0.000000

Appendix 3. Test results from SIC, Electrolux

Dependent Variable: ELUX_STHLM
Method: Least Squares
Date: 05/05/04 Time: 12:38
Sample(adjusted): 7 4700
Included observations: 4214
Excluded observations: 480 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
ELUX_LONDON(-1)	0.066467	0.008046	8.260552	0.0000
ELUX_LONDON(-2)	0.039677	0.008206	4.835151	0.0000
ELUX_LONDON(-3)	0.675828	0.043687	15.46969	0.0000
ELUX_LONDON(-4)	0.218417	0.042346	5.157949	0.0000
C	-0.075304	0.238397	-0.315876	0.7521

R-squared	0.991140	Mean dependent var	163.2962
Adjusted R-squared	0.991132	S.D. dependent var	7.240467
S.E. of regression	0.681833	Akaike info criterion	2.073123
Sum squared resid	1956.750	Schwarz criterion	2.080653
Log likelihood	-4363.069	F-statistic	117718.1
Durbin-Watson stat	0.147666	Prob(F-statistic)	0.000000

Appendix 4. Test result from Augmented Dickey-Fuller, Electrolux

ADF Test Statistic	-30.29851	1% Critical Value*	-3.4349
		5% Critical Value	-2.8627
		10% Critical Value	-2.5674

*MacKinnon critical values for rejection of hypothesis of a unit root.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(ELUX_STHLM_ADF,2)
Method: Least Squares
Date: 05/05/04 Time: 14:22
Sample(adjusted): 7 4704
Included observations: 4698 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(ELUX_STHLM_ADF(-1))	-0.905054	0.029871	-30.29851	0.0000
D(ELUX_STHLM_ADF(-1),2)	0.038811	0.026690	1.454159	0.1460
D(ELUX_STHLM_ADF(-2),2)	0.024746	0.023183	1.067403	0.2858
D(ELUX_STHLM_ADF(-3),2)	-0.001527	0.019302	-0.079126	0.9369
D(ELUX_STHLM_ADF(-4),2)	-0.018179	0.014589	-1.246066	0.2128
C	-0.004269	0.003464	-1.232496	0.2178

R-squared	0.435151	Mean dependent var	-7.98E-05
Adjusted R-squared	0.434549	S.D. dependent var	0.315460

S.E. of regression	0.237215	Akaike info criterion	-0.038425
Sum squared resid	264.0228	Schwarz criterion	-0.030182
Log likelihood	96.26145	F-statistic	722.9289
Durbin-Watson stat	1.998220	Prob(F-statistic)	0.000000

Appendix 5. Test result from Johansen ML procedure, Electrolux

Date: 05/17/04 Time: 13:28
Sample(adjusted): 73 4699
Included observations: 912
Excluded observations: 3715 after adjusting endpoints
Trend assumption: No deterministic trend (restricted constant)
Series: ELUX_LONDON ELUX_STHLM ELUX_NASDAQ
Lags interval (in first differences): 1 to 5

Unrestricted Cointegration Rank Test

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	5 Percent Critical Value	1 Percent Critical Value
None **	0.140130	144.5475	34.91	41.07
At most 1	0.006148	6.859051	19.96	24.60
At most 2	0.001353	1.234942	9.24	12.97

*(**) denotes rejection of the hypothesis at the 5%(1%) level
Trace test indicates 1 cointegrating equation(s) at both 5% and 1% levels

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	5 Percent Critical Value	1 Percent Critical Value
None **	0.140130	137.6884	22.00	26.81
At most 1	0.006148	5.624109	15.67	20.20
At most 2	0.001353	1.234942	9.24	12.97

*(**) denotes rejection of the hypothesis at the 5%(1%) level
Max-eigenvalue test indicates 1 cointegrating equation(s) at both 5% and 1% levels

Unrestricted Cointegrating Coefficients (normalized by b'*S11*b=I):

ELUX_LONDON	ELUX_STHLM	ELUX_NASDAQ	C
0.406185	3.262295	-3.682134	2.428357
-0.155751	0.490778	-0.310792	-2.949175
-1.211983	1.793809	-0.524900	-9.473358

Unrestricted Adjustment Coefficients (alpha):

	0.018841	-0.090885	0.090649

DON)			
D(ELUX_STHLM)	-0.011270	-0.014204	-0.002314
D(ELUX_NASDAQ)	0.055337	-0.009142	-0.001847

1 Cointegrating Equation(s):	Log likelihood	-1589.095

Normalized cointegrating coefficients (std.err. in parentheses)

ELUX_LONDON	ELUX_STHLM	ELUX_NASDAQ	C
1.000000	8.031542	-9.065156	5.978445
	(0.75395)	(0.75555)	(4.60319)

Adjustment coefficients (std.err. in parentheses)

D(ELUX_LONDON)	0.007653
	(0.03696)
D(ELUX_STHLM)	-0.004578
	(0.00263)
D(ELUX_NASDAQ)	0.022477
	(0.00254)

Appendix 6. Test result from Vector Error Correction, Electrolux

Vector Error Correction Estimates
Date: 05/21/04 Time: 11:40
Sample(adjusted): 73 4699
Included observations: 912
Excluded observations: 3715 after adjusting endpoints
Standard errors in ( ) & t-statistics in [ ]

Cointegrating Eq:	CointEq1
ELUX_STHLM(-1)	1.000000
ELUX_LONDON(-1)	0.124509
	(0.03715)
	[3.35135]
ELUX_NASDAQ(-1)	-1.128694
	(0.03700)
	[-30.5075]
C	0.744371
	(0.57458)

	[1.29550]		
Error Correction:	D(ELUX_STHLM)	D(ELUX_LONDON)	D(ELUX_NASDAQ)
CointEq1	-0.036765	0.061463	0.180524
	(0.02112)	(0.29684)	(0.02036)
	[-1.74083]	[0.20706]	[8.86607]
D(ELUX_STHLM(-1))	0.115791	1.033055	0.114178
	(0.03713)	(0.52191)	(0.03580)
	[3.11829]	[1.97937]	[3.18936]
D(ELUX_STHLM(-2))	0.085691	0.727748	0.055599
	(0.04477)	(0.62921)	(0.04316)
	[1.91417]	[1.15660]	[1.28820]
D(ELUX_STHLM(-3))	0.008047	0.978537	0.028072
	(0.04592)	(0.64535)	(0.04427)
	[0.17527]	[1.51628]	[0.63415]
D(ELUX_STHLM(-4))	0.022593	-0.130133	0.053263
	(0.04652)	(0.65383)	(0.04485)
	[0.48569]	[-0.19903]	[1.18762]
D(ELUX_STHLM(-5))	-0.077202	-0.136289	-0.004954
	(0.04557)	(0.64055)	(0.04394)
	[-1.69400]	[-0.21277]	[-0.11274]
D(ELUX_LONDON(-1))	0.010966	-0.998298	-0.020513
	(0.00360)	(0.05058)	(0.00347)
	[3.04756]	[-19.7381]	[-5.91283]
D(ELUX_LONDON(-2))	-0.093599	-0.762343	-0.086254
	(0.03263)	(0.45856)	(0.03145)
	[-2.86893]	[-1.66249]	[-2.74224]
D(ELUX_LONDON(-3))	-0.011736	-0.678613	-0.023098
	(0.03404)	(0.47850)	(0.03282)
	[-0.34473]	[-1.41822]	[-0.70373]
D(ELUX_LONDON(-4))	-0.005340	-0.169423	-0.033722
	(0.03438)	(0.48321)	(0.03314)
	[-0.15532]	[-0.35062]	[-1.01740]
D(ELUX_LONDON(-5))	0.017212	0.269937	-0.018762
	(0.03307)	(0.46481)	(0.03188)
	[0.52045]	[0.58074]	[-0.58845]
D(ELUX_NASDAQ(-1))	0.107332	-0.187703	0.141416
	(0.03168)	(0.44524)	(0.03054)

	[3.38826]	[-0.42158]	[4.63048]
D(ELUX_NASDAQ(-2))	-0.060458	-0.037296	-0.041810
	(0.03137)	(0.44090)	(0.03024)
	[-1.92731]	[-0.08459]	[-1.38249]
D(ELUX_NASDAQ(-3))	-0.007952	-0.087920	0.005382
	(0.03039)	(0.42717)	(0.02930)
	[-0.26165]	[-0.20582]	[0.18369]
D(ELUX_NASDAQ(-4))	0.072154	0.042673	-0.021599
	(0.03010)	(0.42309)	(0.02902)
	[2.39699]	[0.10086]	[-0.74425]
D(ELUX_NASDAQ(-5))	-0.024551	-0.104057	0.032991
	(0.02927)	(0.41142)	(0.02822)
	[-0.83873]	[-0.25292]	[1.16904]
R-squared	0.064534	0.493400	0.147174
Adj. R-squared	0.048874	0.484919	0.132897
Sum sq. resids	34.24680	6765.508	31.83204
S.E. equation	0.195504	2.747870	0.188486
F-statistic	4.120774	58.17702	10.30829
Log likelihood	202.5414	-2207.874	235.8840
Akaike AIC	-0.409082	4.876917	-0.482202
Schwarz SC	-0.324597	4.961402	-0.397717
Mean dependent	-0.015488	-0.016818	-0.017104
S.D. dependent	0.200464	3.828764	0.202415

Determinant Residual Covariance	0.006904
Log Likelihood	-1589.095
Log Likelihood (d.f. adjusted)	-1613.308
Akaike Information Criteria	3.651991
Schwarz Criteria	3.926567