European Bioenergy Markets: Integration and Price Convergence

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Abstract

Energy market integration is beneficial in several ways: it can increase competition, reduce the risk of local shortages or oversupply and can also reduce price volatility. As demand for renewable energy is growing, bioenergy from solid biomass fuels is changing from its traditional role as a locally utilized form of energy into an internationally traded energy commodity. However, there is still not very much knowledge about how bioenergy markets function in terms of price mechanisms and the interconnections between international trade and price development. The aim of this thesis is to investigate the progress of European bioenergy market integration. The thesis is based on two papers in which the progress of European bioenergy market integration is assessed by studying two sub-markets. The degree of market integration is investigated by using time series analysis of bioenergy prices. This makes it possible to investigate if and how developments in national markets influence each other. **Paper I** investigates whether the residential markets for wood pellets in Austria, Germany and Sweden can be considered integrated. The conclusion is that whereas the German and the Austrian markets are integrated, Sweden is a separate market. In **paper II**, the market for unrefined wood fuels in the Baltic Sea area is studied. The subject here is to investigate the level of wood fuel market integration between Estonia, Finland and Sweden by analyzing whether there is short-run or long-run convergence between prices in the three countries. The conclusion is that although the price difference between the countries has decreased a great deal during the time period in focus, the markets can not be considered integrated. These two studies show that although trade has indeed contributed to increased bioenergy market integration in Europe, there is still a way to go until there is a common European bioenergy market. As data availability is continuously increasing, it will be possible to expand future research to the situation in more countries on a both small and large scale. Thereby it will be possible to get a more comprehensive view of the status of European bioenergy market integration.

Keywords: bioenergy markets, bioenergy prices, bioenergy trade, cointegration, energy market integration, price convergence, solid biofuels, time series analysis, wood fuels, wood pellets

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Dedication

To Kajsa.

Contents

List of included publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Olsson O., Hillring B. & Vinterbäck J. (2009). European Wood Pellet Market Integration – A Study of the Residential Sector. Submitted to *Biomass & Bioenergy*

II Olsson O., Hillring B. & Vinterbäck J. (2009). Wood Fuel Market Integration and Price Convergence in the Baltic Sea Area. (Manuscript)

The contribution of Olle Olsson to the papers included in this thesis was as follows:

Paper I: Olsson: 70%, Hillring: 15%, Vinterbäck:15%

Paper II: Olsson:70%, Hillring 15%, Vinterbäck: 15%

Selected other publications (not included in this thesis)

Hartkamp R., Hillring B., Mabee W., Olsson O., Skog K., Spelter H., Vinterbäck J., Wahl A. 2009. "Continued growth expected for wood energy despite turbulence of the economic crisis: Wood energy markets, 2008-2009" in: *UNECE/FAO Forest Products Annual Market Review, 2008-2009*. 97-110 ISBN 978-92-1-117007-8

Hillring B., Levin A, Olsson O, Sukhanov V. "Prospects for wood bioenergy development in the Russian Federation, Europe and North America" in *Forest Bioenergy – manual for graduate and post-graduate studies*, MSFU Publishers, Moscow, 2008

Hillring B., Olsson O., Gaston C., Mabee W., Skog, K., Spelter, H. , Stern T. , "Record fossil-fuel prices drive wood energy markets: Wood energy markets in the UNECE region 2007-2008" in *UNECE/FAO Forest Products Annual Market Review 2007-2008* s.95-105, ISBN 978-92-1-16990-4

Hillring B., Olsson O. 2007. "Biobränslen kors och tvärs över gränserna." In*: Bioenergi - till vad och hur mycket?*. Formas förlag, 79-88
ISBN 978-91-540-5995-9

Hillring B., Canals G., Olsson O. 2007. "Markets for Recovered Wood in Europe - an overview" In: *3rd European COST E31 Conference Management of Recovered Wood*. 201-214, ISBN 978-960-12-1596-9

Holmgren K., Eriksson E., Olsson O., Olsson M., Hillring B., Parikka M. 2007. *Biofuels and climate neutrality – system analysis of production and utilisation.* (Elforsk rapport 07:35)

Abbreviations

CEN	European Committee for Standardization
DEPV	German Energy Pellet Association
EC	European Community
ECSC	European Coal and Steel Community
EEA	European Environmental Agency
EEC	European Economic Community
EEK	Estonian Kroon (the national currency of Estonia)
EROEI	Energy Return On Energy Invested
EU	European Union
Euratom	European Atomic Energy Community
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
LNG	Liquefied Natural Gas
LOP	Law of One Price
OPEC	Organization of Petroleum Exporting Countries
SECA	Special Emission Control Area
SEK	Swedish Krona (the national currency of Sweden)
SLU	Swedish University of Agricultural Sciences
VAR	Vector Auto Regression

1 Introduction

With high oil prices and increasing awareness of anthropogenic global warming due to emissions from combustion of fossil fuels, demand for bioenergy in Europe has increased dramatically in the first decade of 21^{st} century. This has also led to an increase in biomass trade with large biomass trade flows not only within Europe, but also with biomass from the Americas, Russia, South-East Asia and Africa. This increased trade in bioenergy is a positive development, since it can enable cost-effective reductions in greenhouse gas emissions and reduce dependency on increasingly scarce and price-volatile fossil fuels (Junginger et al. 2008; Lundmark & Mansikkasalo 2009). However, despite the rapid growth of bioenergy markets there is still a lack of knowledge about how bioenergy markets function, especially in terms of price formation, market integration and how trade flows affect price development in different regions. These issues may be expected to become increasingly important as bioenergy markets grow and in the context of EU policy directed at creating an integrated European market for energy. The aim of this thesis is to contribute to the understanding of how European bioenergy markets by investigating the level of European bioenergy integration through studies of price interconnections between national markets.

1.1 Bioenergy

Bioenergy is extracted from *biofuels*, a term which in this thesis includes all forms of biomass utilized for energy purposes. The focus herein will be on *solid biofuels*, and in particular *wood fuels*, i.e. solid biofuels consisting of woody biomass (CEN 2004). Wood fuels are predominantly used in different forms of stationary energy conversion for production of electricity, steam or heat.

Biomass was one of the first resources utilized for energy purposes by humankind. Its importance throughout history can hardly be overstated, having provided humanity with energy for many thousands of years. However, during the last 100 years, the share of bioenergy in the global energy mix has decreased from about one-third in the early 1900's to roughly 10% in 2006 (Smil 2003; IEA 2008). The reason for this decrease is largely the massive increase in the use of fossil fuels that has taken place during this time period. Global energy consumption has increased tenfold since the beginning of the 20^{th} century, a process that has been dominated by the growth of coal, oil and natural gas.

However, it has become clear that the 21^{st} century can not mimic the growth in fossil fuel consumption that took place during the 1900's. First of all, fossil fuels are non-renewable. The rate of depletion of the current reserve stock greatly exceeds the rate at which new reserves are being formed. Second, the combustion of fossil fuels leads to the emission of large amounts of carbon dioxide (CO_2) into the atmosphere. The increase in anthropogenic emissions of CO_2 is, according to the Intergovernmental Panel of Climate Change (IPCC), believed to have been a cause for the increase in global average temperature that has occurred during the 20^{th} century. It is generally accepted that in order to avoid dangerous levels of climate change, emissions of fossil CO_2 need to be reduced (IPCC 2007).

1.2 Bioenergy in the European energy system

Bioenergy is seen as an important part of future EU energy policy because it can be a solution to many of the problems of fossil fuels. To begin with, bioenergy is a renewable form of energy which is an important factor in light of the debate on the eventual depletion of fossil fuel resources.[1] Second, bioenergy does not contribute to the net increase of CO_2 in the atmosphere, provided that production is conducted in a sustainable manner, i.e. that harvest does not exceed growth and that soil issues are handled properly (Holmgren et al. 2007). Third, since bioenergy resources are not as concentrated geographically as oil and gas, an increased share of bioenergy in the energy mix can be an important tool to mitigate the problems of energy supply security. This third issue is a vital part of EU energy policy (European Commission, 2000). Although dependence on energy imports

[1] Note that there are with radically different views on how acute the problem of resource depletion is (see e.g. Deffeyes 2003; Huber & Mills 2005)

need not be a problem if supply is stable and reliable, this is not always the case. The turbulence in recent years concerning the flow of Russian natural gas through Belarus and Ukraine has increased concerns among European policymakers and citizens about the dangers of being overly dependent on imported energy (see e.g. Pirani et al. (2009)

Renewable sources of energy currently play a minor role in the European energy system. Fossil fuels and nuclear energy make up more than 90% of total primary energy supply and almost 85% of electricity production in the EU. The share of bioenergy is about 4% of total energy supply and 2% of electricity production. (IEA 2008a; IEA 2009) However, the share of bioenergy varies greatly between the member states, as can be seen in Figure 1 below.

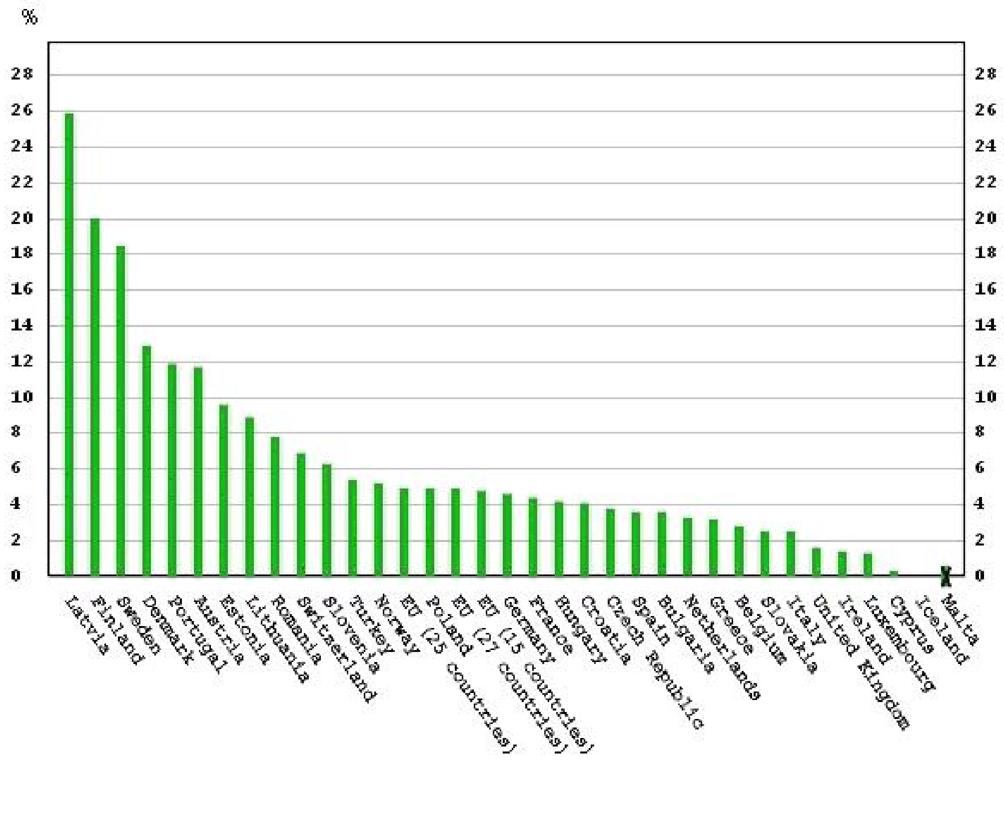

Figure 1. Share of "Biomass & waste" in gross inland energy consumption in EU-27 + Iceland, Norway, Switzerland & Turkey (Eurostat 2008)

In countries such as Latvia, Finland and Sweden, bioenergy is a vital part of the energy system, whereas the contribution of bioenergy in Malta, Cyprus, Ireland, Luxembourg and the United Kingdom is very small. Although several factors may determine the success of bioenergy implementation (see Roos et al. (1999) for more on this topic), one may note that countries with a large forest cover such as Sweden, Austria and Finland all have a high percentage of bioenergy in their respective energy systems. In the light of the ambitious goals set for the member countries in the 2008 EU energy and climate package (Council of the European Union 2009) it may however be expected that more countries will attempt to increase the share of bioenergy in their respective energy mixes.

1.3 European policy on energy market integration – a short history

One of the driving ideas behind the European Union is the belief in the virtues of a European common market for goods, services, capital and labour. The first steps towards the EU-27 of today were taken in the early 1950's with the creation of the European Coal and Steel Community. Since then, the member states have continuously become more and more integrated with each other through a range of measures of trade liberalization and legal harmonisation. However, despite the fact that energy was a key issue from the very origins of the EU (European **Coal** and Steel Community, Euratom), the integration of European energy markets was little more than a symbolic issue before the 1970's (Correljé et al. 1999a). Although there existed e.g. cross-border electric transmission cables, cooperation was rarely based upon political decisions aimed at promoting free trade in electricity, but rather on technical considerations at the operational level. The main reason for the relative lack of political interest in energy market integration was the conflict between a) the economical benefits of market integration and b) the objective for nations to be as energy-independent as possible. Energy was - and is - not just an issue of economics but one of national security as well. Hence, countries were reluctant to surrender national sovereignty over domestic energy resources and infrastructure, regardless of the advantages to Europe as a whole. The oil crises of the 1970's did however make it clear to European policy makers that there was definitely a need for more cooperation and coordination on energy policy (Weyman-Jones 1986; Molle 2006).

In 1988, an EU report entitled *The Internal Energy Market* (European Commission 1988) was released. The report in relatively frank terms addresses the lack of progress in European energy market integration thus far and lays out the steps that were need to be taken to facilitate European energy market integration. The report became a starting point for legislative processes aiming to integrate Europe's energy markets. From the late 1980's and onwards, a range of EU directives laying out the plans for energy market reform were presented, e.g. in the 1996 Electricity Directive 96/92/EC (European Commission 1997) and the 1998 Gas Directive 98/30/EC (European Commission 1998).

However, the drive towards increased integration in European energy markets has hitherto been focused mainly on gas and electricity. The reason for this is the specific circumstances in integrating grid-based energy markets. Furthermore, coal and oil, the other two major energy markets,

> …have always been traded in a relatively 'free' environment (ignoring for occasional cartels and other specific institutional and market structure related barriers) […] [An] important factor is that the transport infrastructure is not asset specific but rather flexible. This, in combination with the fact that there always been numerous suppliers, has reduced governments' fears for a lock-in effect (Correljé et al. 1999b, p.7).

1.4 Objective: the integration of European bioenergy markets

The integration of the European markets for bioenergy is a process that hitherto has been discussed only to a very small degree in EU policy on the integration of energy markets. A likely explanation is that when the process towards a common European market for energy was set at foot in the 1980's, bioenergy only had a marginal share of primary energy supply. Although fossil fuels still dominate the EU energy system, bioenergy is rapidly increasing its share. Furthermore, the rationale behind the promotion of market integration for gas and electricity is equally viable for bioenergy markets. Moreover, increased bioenergy market integration is likely to alleviate the reduction of dependency on fossil fuels (Lundmark & Mansikkasalo 2009). The objective of this thesis is to assess the level of integration between European bioenergy markets through two studies of sub-markets for bioenergy in Europe: the residential wood pellet market and the large scale market for unrefined wood fuels.

2 Materials and methods

2.1 Bioenergy markets

Traditionally, bioenergy has been a regional form of energy in the sense that it has been utilized close to the source of the fuel. Today, this is still the case for a large part of the world's population – particularly in developing countries – that relies on local biomass for daily needs of energy for cooking and heating. However, since the 1970's oil crises, bioenergy has increasingly become a commercial form of energy, used on an industrial scale. In Sweden, an increased use of bioenergy, especially in the forest industry and in the district heating sector, was an important part of the strategy to decrease the country's dependence on imported oil (Björheden 2006). Similar strategies were used in other forest-rich countries such as Austria (Kranzl et al. 2009) and Finland (Helynen 2004). This trend of increasing bioenergy consumption has continued through the 1990's and early 2000's due to concerns about anthropogenic global warming and high fossil fuel prices. Between 1990 and 2007, the share of biomass and waste in gross inland energy consumption in the EU-27 countries doubled, from 2.7% to 5.4% (Eurostat 2008).

The increasing demand for bioenergy has also led to increased. Large-scale long-distance trade of solid biofuels first originated in Sweden. Swedish district heating plants started importing biofuels in the 1990's from both relatively nearby countries such as Estonia, Latvia and Germany, as well as from the West Coast of Canada (Hillring & Vinterbäck 2000; Ericsson & Nilsson 2004). It has been estimated that in 2003, more than 23% of biofuels used in Swedish district heating were imported (Olsson 2006).

2.1.1 Bioenergy market research – literature overview

A problem with studies of bioenergy markets compared to other energy markets is the lack of readily available information on available resources, trade flows and prices for different biofuel assortments. This is an issue that not only presents an obstacle for academic inquiries into bioenergy markets, but one that also is a barrier to the actual development of the markets (Junginger et al. 2006). However, since the 1990's, bioenergy market research has made progress and dealt with a number of important issues, some of which are reviewed below.

Supply potentials

Demand for bioenergy is expected to continue to grow in the foreseeable future as the world aims to wean itself off fossil fuels. Consequentially, the question of future potentials for bioenergy **supply** becomes vital in order to assess the contribution that can realistically be expected from bioenergy in the future global energy system. Several studies of the topic have been conducted. Berndes et al. (2003) made a review of 17 different studies of future bioenergy potential and concluded that estimations of future potential range between 100 and 400 EJ per annum.[2] In a more recent study, Lysen & van Egmond (2008) review eight post-2003 studies of global bioenergy potential and find an even wider range: 0-1500 EJ per annum.[3]As for European bioenergy potentials, studies find the potential to lie between 3.4 and 17.2 EJ (EEA 2006; Ericsson & Nilsson 2006; de Wit & Faaij 2008).

Bioenergy trade

Whereas the estimates of the total amount of global potential for bioenergy differ significantly, there is more consensus as to how global bioenergy trade flows will develop in the long run. Both Hansson et al. (2006) and Smeets et al. (2007) point to Latin America, Oceania, Africa and the former USSR as the regions most likely to become exporters of bioenergy. According to Hansson et al. (2006), North America, Western Europe and the Southern and South-Eastern subregions of Asia are most likely to become net importers of bioenergy. As for intra-European bioenergy trade, Lundmark & Mansikkasalo (2009) estimate that EU policies regarding energy and climate change will bring about an up to 67% increase in internal EU trade in forest fuels.

[2] Total global energy demand in 2006 was roughly 490 EJ. (IEA 2008b)

[3] Assumptions about e.g. agricultural productivity and technological development are highly influential in these enormously dissimilar conclusions.

International transport of bioenergy

Since bioenergy trade is limited to non-grid transportation systems[4], bioenergy trade is similar to trade in coal and oil in that market barriers are found in institutional and structural phenomena rather than in physical connections (see section 1.3.2). Transportation issues are nevertheless vital in bioenergy trade, since solid biofuels in general are bulky and have a low value-to-volume ratio. For this reason, international trade in bioenergy has relied heavily on ship transport, which is very cost efficient compared to train and especially to truck transport (see Table 1).[5]

Table 1. *Wood pellet transport costs in €/metric ton (Pigaht et al. 2005)*

Mode of transport	Distance	Cost
Truck (40 tons)	500 km	€ 25.4/ton
Train (1000 tons)	2000 km	€ 20.5/ton
Ship (22 000 tons)	10 000 km	€ 21/ton

This means that long-range bioenergy trade is economically feasible given that transport costs are lower than the difference in prices between the export country and the import country. However, there has been some debate on the environmental impact and Energy Return On Energy Invested (EROEI) of bioenergy trade. The issue has been analyzed in a number of studies, often with the transatlantic trade of wood pellets from North America to Europe in focus. The results do however differ rather significantly. Whereas Damen & Faaij (2003) find that the energy requirements in the wood pellet production-and-transportation chain from Canada to the Netherlands account for 10-11% of the energy content in the wood pellets, Magelli et al. (2009) estimate the same figure to 39% when analyzing import to Sweden from Canada. Furthermore, the latter study finds that more than 2 kg of sulfur oxides is released per ton of wood pellets transported from Canada to Sweden, due to the high sulfur content in the bunker fuel used for ships. [6]

[4] For an interesting example of experiments on pipeline transport of solid biomass, see Kumar et al. (2004)

[5] A wood pellet is a *biofuel pellet* - "a densified biofuel made from pulverised biomass with or without pressing aids usually with a cylindrical form, random length typically 5 to 30 mm, and broken ends" (CEN, 2004) – made from woody biomass.

[6] As a reference, it may be noted that an automobile that drives 15 000 km releases about 0.1 kg of sulphur oxides (Vidal 2009).

Bioenergy prices

In the early stages of bioenergy development (i.e. before the oil crises of the 1970s) both production and consumption was very labour-intensive which meant that the price of bioenergy primarily depended on the price of labour. Hence, during time periods of rapid wage increases, the high cost of production, transportation and consumption of bioenergy meant that it lost in competitiveness compared to other energy carriers such as fossil fuels (Schön 1992). As bioenergy has become increasingly commercialized in the last 30 years, this has however changed. An interesting study of present-time bioenergy price formation was conducted by Hedman (1992). The study concluded that for wood chips from cutting residues, the price was set by the cost of production. For sawmill residues, the price was more dependent on the price that competing users, e.g. the particle board industry, was capable of paying. As for refined fuels, such as wood pellets and briquettes, the conclusion from the study was that the price was mainly set by costs of production, although the price of heating oil would serve as the ceiling for how far the price of refined fuels could go. The development of Swedish bioenergy prices in the 1990's was analyzed in two papers by Hillring (1997; 1999). The studies noted that the rapid increase of the share of bioenergy in Swedish district heating was a result of expensive fossil fuels due to heavy environmental taxation. However, the price of the solid biofuels was rather stable all through the 1990's, which in effect meant a decrease in real prices for unrefined wood fuels such as wood chips (see Figure 2). This development was largely due to good supply of residues from the forest industry that was able to balance the increasing demand.

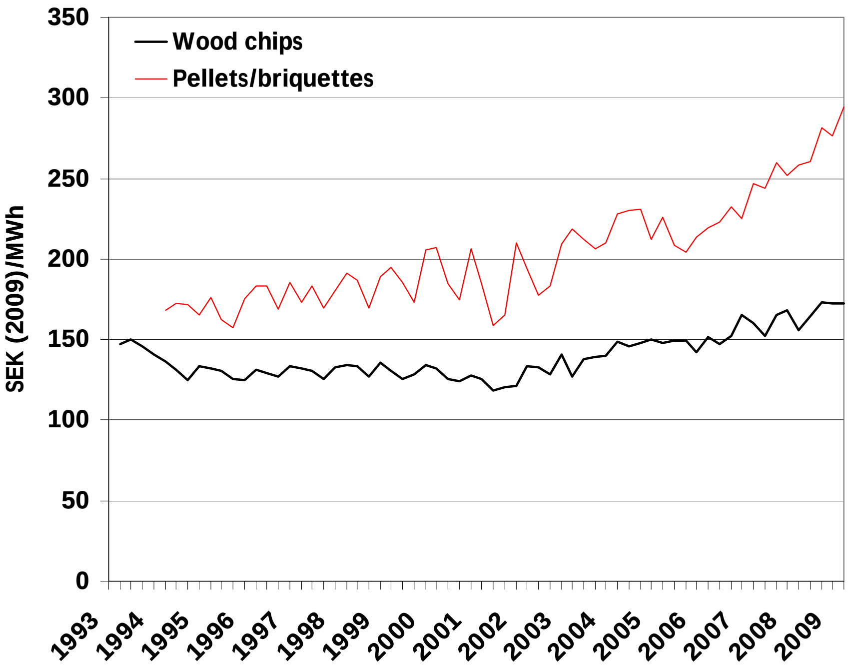

Figure 2. Inflation-adjusted wood energy prices in Sweden 1993-2009. (Swedish Energy Agency 2009)

In a study that briefly touched on the topic for this thesis, (Dahl 2005) raised the prospect that increased trade in wood pellets and increased market transparency should lead to gradual price convergence between national markets in Europe. The study deduces that this should eventually lead to a common "European price" for wood pellets. Hedenus et al. (2009) discuss price formation of solid biofuels with focus on comparing the effect of oil price volatility on residential wood pellet prices and bioethanol prices, respectively. The study finds that there

> "…is no statistically significant relation between the pellet prices and the oil prices, even though there is some co-movement in 2006 and 2007." (Hedenus et al. 2009, p.5)

As for the sensitivity of the consumers of bioenergy to fluctuations in prices, Lundmark (2009) finds that energy sector demand for biomass is relatively insensitive to price increases. Energy sector demand for fossil fuels is more sensitive to price increases, as is the demand for biomass from the forest industry sector.

2.2 Market integration research – a literature survey

According to economic theory, market integration is generally seen as a positive development. As previously isolated economic markets are integrated, the number of market actors may increase which leads to increased specialization, more competition and more economic efficiency (Berg & Lewer 2006). Furthermore – and this is especially important for strategic goods such as energy – market integration can also be a way to increase security of supply (and demand). An increased number of market actors reduces the vulnerability which comes as a consequence of being overly dependent on a single supplier or customer.[7] It has also been shown (Jacks et al. 2009) that market integration contributes to decreased volatility in commodity prices, as prices become less vulnerable to local disturbances in supply or demand. However, increased market integration is not without problems. The concept of market integration by nature implies that markets become increasingly dependent on each other. Hence, market events in geographically distant regions may have large effects on each other. Such processes are commonplace in the world oil market as well as in the world financial markets which the financial turbulence in the autumn of 2008 made clear (see e.g Norberg 2009).

This section will shortly review the relevant literature on market integration in traditional fuels (oil, gas & coal) and forest markets. The inclusion of the latter category might seem odd given the focus on energy market integration in this thesis. However, since bioenergy markets are connected to the markets for forest products in terms of e.g. common sources of supply and similar logistical systems, they are important to include.

2.2.1 Energy market integration

Oil market integration

The debate on whether the oil market really is globally integrated originated with the article "International Oil Agreements" (Adelman 1984) , in which the author states that

[7] An example is the discussions regarding the construction of a trans-Baltic Sea electric cable from Sweden to Lithuania as a means to further integrate Estonia, Latvia & Lithuania with the Nordic Electricity market to reduce the Baltic Countries' dependence on Russian energy. (Reuters 2009)

> "…the world oil market, like the world ocean, is one great pool […], oil should flow toward those places where total oil supply is scarcest and the price highest" (Adelman 1984, p.5)

Adelman states this as if it was a commonly accepted notion, but the issue has been the focus of a long series of academic studies, beginning with Weiner (1991) who contested Adelman's claim and asserted that the world's oil markets were in fact regionalized. Throughout the 1990's and the first decade of the 2000's, many authors have contributed to the debate (Sauer 1994; Ripple & Wilamoski 1996; Gulen 1997; Gulen 1999; Kim et al. 2007) and the consensus seems now to be that Adelman was correct in his original assertion that the world indeed constitutes a single market for crude oil.

Coal market integration

Research concerning the degree of integration in the global coal markets, started off in a manner similar to how research on the existence of a global oil market began. Commentators have for some time made the casual assumption that the world market for coal indeed is integrated (Ellerman 1995), but in recent years more formal analyses have been conducted. Interestingly, the conclusions differ somewhat. Whereas Li (2008) comes to the conclusion that the world by and large constitutes an integrated market for steam coal, Wårell (2006) finds that although Japan and Europe previously were integrated into one market, they were separate markets in 2000.

Natural gas market integration

The dominance of pipelines for transport of natural gas, combined with the strong presence of national gas monopolies, has meant that gas markets are nowhere as near as global as oil markets. In fact, research has mainly been focused on analyzing whether the European and North American markets are integrated within themselves.

The North American natural gas market has been analyzed by use of time series analysis in a number of studies (De Vany & Walls 1993; King & Cuc 1996; Serletis 1997; Brown & Yücel 2008). The results point to the conclusion that North America can not be considered an integrated market for natural gas.

The European natural gas markets have traditionally been separated according to country borders. However, as was discussed in section 1.3, a key component of EU energy policy is the integration of EU natural gas markets through a process both of deregulation and liberalization as well as by the construction of new pipelines. Hence, studies have been made in recent years that aim to determine the progress of EU natural gas market integration. Judging by the studies that have been made (Asche et al. 2002; Siliverstovs et al. 2005; Neumann et al. 2006; Robinson 2007), it is yet too early to consider the European natural gas markets fully integrated, but the trend seems to be towards increased integration.

The market for Liquefied Natural Gas (LNG) transported by ship, represents only a minor share of international trade in natural gas (although LNG is the dominating mode of transport in East Asia) (Rosendahl & Sagen 2007). LNG is however becoming an increasingly attractive alternative, especially since the costs of liquefication, re-gasification and transport are estimated to continue decrease in coming years (Gilardoni 2008). If LNG continues to increase its share of the global trade in natural gas, it may be expected that the world become an increasingly integrated market for natural gas as well. At present time however, it seems to have had little effect on mitigating the lack of market integration between continents, as is shown by Siliverstovs et al. (2005).

2.2.2 Forest product market integration in Europe

The forest product markets of Europe have been studied in a wide range of papers, with a particular focus on the North European markets. Riis (1996) concluded that the Swedish and Danish markets for spruce timber are integrated. Thorsen (1998) found the markets for coniferous timber in Denmark, Finland, Norway and Sweden to be integrated, with Sweden and Finland acting as price-leaders. In the first of a number of Finnish studies of North European timber market integration, Toppinen & Toivonen (1998) studied the domestic Finnish market for timber and concluded that the market for pine sawlogs to be fully integrated. However, in the markets for spruce sawlogs, pine pulpwood and spruce pulpwood, the authors found some regional separation. Mäki-Hakola (2002) studied market integration for five different timber assortments in Estonia, Finland, Germany and Lithuania. Only the markets for pine pulpwood were found to be fully integrated, although the markets for birch pulpwood and spruce pulpwood showed signs of partial integration. There were no signs of market integration for sawlogs. Toivonen et al. (2002) studied roundwood markets in Austria, Finland and Sweden. The conclusion was that the Swedish and

Finnish markets were largely integrated, with Finland acting as a price-leader. Austria, however, was found to be a market separate from the two Nordic countries. Toppinen et al. (2004) examined relationships between Estonian and Finnish timber prices but found no clear evidence of market integration, although the authors emphasized that prices in the two countries were indeed trending toward each other, i.e. there were signs of long-run price convergence (see section 2.4.2). In a later study, Toppinen et al. (2005) investigated the markets for roundwood in Estonia, Finland and Lithuania. The only market that was found to be common for the three countries was the market for spruce sawlogs. Hänninen et al. (2006) studied forest markets in Austria, the Czech Republic, Estonia and Finland to assess the order of market integration between "old and new EU countries". Although the markets still showed signs of separation, the authors concluded that there was a trend of long-run convergence, which was taken as a sign of gradual integration of European forest markets. Finally, Mutanen & Toppinen (2007) studied the relation between Russian and Finnish timber markets and found signs of market integration for spruce sawlogs, but not for other assortments.

2.3 Market integration and prices

In order to study whether markets are integrated in the sense that events in one market spill over into the other, a common method is to analyze price developments and possible price interconnections between markets.

If a market is functioning efficiently, price development will reflect the balance of supply and demand. This enables the use of price information to define the boundaries of a market and thus to define what a "market" is. Marshall (1920) writes that

> …the more nearly perfect a market is, the stronger is the tendency for the same price to be paid for the same thing at the same time in all parts of the market: but of course if the market is large, allowance must be made for the expense of delivering the goods to different purchasers; each of whom must be supposed to pay in addition to the market price a special charge on account of delivery (Marshall 1920)

Hence, if the price of a certain good in two regions is the same – or rather, that the prices remain approximately similar over time - we may conclude that the two regions constitute a common market for the good in question (Stigler & Sherwin 1985).

This idea is naturally connected to the *Law of One Price* (LOP). The LOP says that if markets are efficient, the price of all identical goods should be the same everywhere. This of course assumes that the cost of transportation between two locations is zero formulation and hence this formulation is known as the *Strong Law of One Price*. This assumption is relaxed in the *Weak Law of One Price*, which says that in an efficient market, the price of a good should be uniform everywhere, accounting for transportation costs (Miljkovic 1999).

The Law of One Price and the extent of a market – as discussed by Stigler & Sherwin (1985) - are closely related, and the connection can be formulated as "When the law of one price holds for two markets, the two markets are integrated".

It should however be mentioned that other methods have been utilized in market integration studies. One alternative is to use data on trade flows between countries and the share of imports in a particular market (Elzinga & Hogarty 1973) as basis for analysis. The problem with this approach for bioenergy markets is the lack of comprehensive data on bioenergy trade flows. Information availability is improving, e.g. with the 2009 introduction of a specific international customs code for wood pellets[8]. Hence, future studies may use trade data to complement price studies. Nevertheless, in this thesis, price relationships will be the basis for the empirical analysis and data on trade flows will only be used for illustrative purposes.

2.4 Two forms of price convergence

In the literature on market integration and the Law of One Price the term "price convergence" often comes up. However, there is a potential risk of confusion concerning what is actually meant by "price convergence", since there is a lack of terminological consistency in the literature. Generally, two forms of price convergence may be distinguished: *short run price convergence* and *long run price convergence*. In brief, the difference between the two is whether two regional markets **are** integrated or whether they are **moving towards** market integration (Gluschenko 2005).

[8] 44013020 "Sawdust and wood waste and scrap, agglomerated in *pellets*"

2.4.1 Short run price convergence

The first of the two forms of price convergence concerns the case where two regionally separated areas, e.g. *A* and *B*, are part of the same market, i.e. the two markets are integrated. If this is the case, the price of a certain good in region *A* can not diverge limitlessly from the price of the same good in the region *B*. If the price difference should ever increase to more than the cost of transporting the good between the regions, arbitrage mechanisms[9] will cause this difference to disappear.

Time series analysis has for several decades been a widespread tool used to study this kind of short-run relationships between markets through price series. Before the end of the 1980's, traditional techniques based on Vector Auto Regression (VAR) analysis were most commonly used. The concept of *Granger causality* (Granger 1969) has proved particularly useful. In short, a variable *X* is said to Granger-cause the variable *Y* if the inclusion of past values of *X* provides a better estimation of the present value of *Y* compared to an estimation that simply uses past values of *Y* itself. In studies of market integration, Granger-causality between price series in markets is often interpreted as a sign of the two markets being integrated (see e.g. Cartwright et al. 1989).

With the development of new methods in time series analysis since the late 1980's - beginning with the seminal work by Engle & Granger (1987) - a large number of studies on market integration have been conducted using *cointegration analysis* of time series of prices. If one studies two time series, A and B, which individually are non-stationary – i.e. they have time-dependent statistical properties – it is possible that there exists a linear combination of the two time series that is stationary, i.e. that the mean and variance of the series do not change over time. If such a linear combination exists, the two time series are said to be *cointegrated*. This parallels the concept of the Law of One Price discussed earlier. If two price series are cointegrated, the Law of One Price holds and the markets are integrated[10]. Cointegration analysis of market integration has been used not only in studies of energy markets (e.g in the majority of the studies reviewed in section 2.2.1), but also in markets for fish (Asche et al. 2004), wine (Troncoso-Valverde 2004) and the 18th century Catalonian labour market (Mora-Sitja 2007) to name but a few.

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[9] That is, traders will take advantage of the difference in prices to make a risk-free profit.

[10] It is important to separate the economic concept of "market integration" and the time series analysis concept of cointegration.

2.4.2 Long run price convergence

Long run price convergence is the process *towards* the integration of two separated markets. Long-run convergence basically entails a gradually narrowing gap between the prices in different regions. The study of long run price convergence has its methodological origins in development economics and studies of economic growth (Durlauf & Quah 1999). In these cases, whether or not *incomes* in different regions are converging has been the key research question. However, the methodology and the concepts are well suited for the studies of long-run convergence of prices as well and have been used for this purpose in a number of studies (Ramírez 1999; Gluschenko 2005; Robinson 2007). The measure of long-run convergence used in this thesis is σ (sigma) convergence. Sigma convergence is here measured as the coefficient of variation – the standard deviation divided by the mean – over time for the prices included. If the coefficient of variation is decreasing over time, this means that prices are converging (Gaulier & Haller 2000).

2.5 Data

The data used for the empirical analysis in this study is mainly series of bioenergy prices in different European countries. As was previously discussed (see 2.2), there has been a lack of comprehensive bioenergy market information, which in general also applies to prices, and especially price *series*. However, in certain countries and for certain fuel assortments, prices have been reported and assembled for time periods that are long enough for them to be analyzed by use of time series analysis.

For the study of the European residential market for wood pellets, which is in focus in Paper I, the data consisted of monthly prices between January 2004 and June 2008 on wood pellets for bulk delivery in Austria, Germany and Sweden. The data series was collected and assembled by *DEPV*[11] – the German Energy Pellet Organisation – for the German price statistics, *ProPellets Austria*[12] for the Austrian prices and *ÄFAB*[13] for the Swedish prices.

[11] www.depv.de
[12] www.propellets.at
[13] *Älvdalens Fastbränsle AB*, www.afabinfo.com

The study of wood fuel market integration in the Baltic Sea area in Paper II used quarterly prices on unrefined wood fuels in Estonia, Finland and Estonia from 1998Q1 to 2009Q1. The Estonian prices were taken from a database assembled by *Metla*, the Finnish Forest Research Institute[14]. The Finnish prices were collected by Statistics Finland[15] and the Swedish prices by the Swedish Energy Agency[16]. The analysis in Paper II also includes estimations of shipping costs in the Baltic Sea in order to compare price developments with and without costs of transportation between countries. Series of transportation costs for short-sea shipping[17], which is most common for Baltic Sea bioenergy trade, are not readily available, and there is no cost index available as there is for large bulk transports (e.g. the *Baltic Dry Index*). Instead, the transportation costs were estimated by using figures on August 2009 rates of shipping bioenergy that were provided by an anonymous person involved in Baltic Sea transport of solid biofuels. By combining an index of freight rates for short sea shipping – the class of shipping utilized for bioenergy trade in the Baltic sea - with fluctuations in fuel prices, transport costs estimations were made by extrapolating back from to 2009 to 1998.

In both papers, Estonian and Swedish prices were converted from SEK and EEK to Euros by use of exchange rate statistics from *Riksbanken* (2009).

[14] www.metla.fi
[15] www.stat.fi
[16] www.swedishenergyagency.se
[17] i.e. ships in sizes around 5000 dwt.

3 Results

3.1 Paper I: European Wood Pellet Market Integration – a Study of the Residential Sector

3.1.1 Paper I: Scope and methods

The European market for wood pellets has been growing at a rapid pace since the turn of the 21st century, due mainly to high prices for fossil fuels and the implementation of policy measures aiming to decrease emissions of greenhouse gases. Demand for wood pellets has been steadily increasing both for large scale production of heat and electricity, as well as for small scale production of residential heating in domestic stoves and boilers.

Wood pellet markets first originated in forest-rich countries such as the USA, Sweden and Austria. However, as the benefits of pellets in terms of environmental properties and cost competitiveness - relative to traditional fuels such as oil and natural gas - have become increasingly clear, countries without large domestic forest resources have also aimed to increase pellet consumption. Thus, wood pellets are now utilized in most countries in Europe, including the Netherlands and Belgium, which are among Europe's leading wood pellet consumers but are almost 100% dependent on imports for their pellet supply. This is one example of how wood fuel markets are transforming, changing from their origins as local and national to becoming increasingly international.

According to economic theory, international trade in wood pellets should lead to gradual price convergence across the nations participating in the international wood pellet market. Ultimately, according to the (Weak) *Law* *of One Price* (LOP) the price should be the same in all wood pellet trading countries, allowing for differences due to transport costs. If the Law of One Price holds, the markets are integrated.

In this study, the law of one price is tested for the European market for residential wood pellets. Price series data from Austria, Germany and Sweden is used in combination with cointegration analysis. If two time series are cointegrated, this means that although they may not consistently follow each other's paths, they will never drift away from each other limitlessly. This can be applied to the study of the LOP since if two markets are integrated and the LOP holds, the prices of a certain good in the two regions will never differ more than by transport costs.

3.1.2 Paper I: Main findings

Pairwise cointegration tests were conducted using monthly series of residential wood pellet prices from Austria, Germany and Sweden from January 2004 to June 2008.

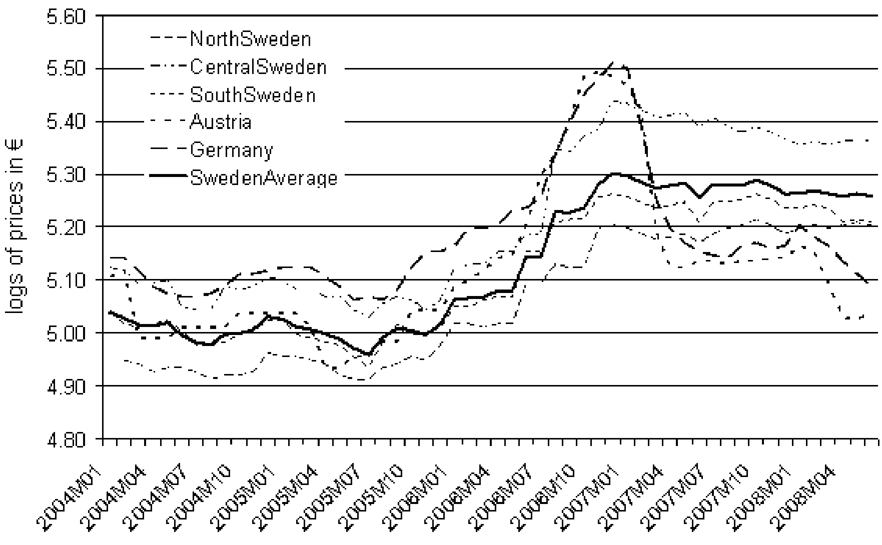

Figure 3. The six price series used as data input (in logarithms and with VAT removed). (Rakos 2007; ÄFAB 2009; Propellets 2009;; DEPV 2009)

The result was that the Austrian and German prices were cointegrated, whereas the Swedish prices were not cointegrated with any of the other two series. However, the Swedish data was divided into three regional series – North, Central and Southern Sweden – and some signs of cointegration between the Swedish regional markets were found. Hence, it may be said that whereas Austria and Germany together constitute an integrated market for residential sector wood pellets, Sweden is not part of this market.

3.1.3 Paper I: Discussion

The reasons why the Austrian and German markets are part of an integrated market for residential wood pellets and Sweden is not, are not clearly discernible. Explanations for the lack of market integration in general literature are several and varying. Excessive transport costs are often named as an important obstacle, and this may also be the case here, although too little research has been conducted in the area to draw solid conclusions as to the separation of the Swedish and the continental wood pellet market. Specifically, the lack of comprehensive and reliable data on wood pellet trade flows between the countries make it difficult to draw conclusions on the precise reasons for the lack of short-run price convergence between Sweden and the other two countries.

3.2 Paper II: Wood Fuel Market Integration and Price Convergence in the Baltic Sea Area (Manuscript)

3.2.1 Paper I: Scope and method

Many of the countries in the Baltic Sea region have among the highest shares of bioenergy in their energy mixes of all EU countries. Furthermore, the Baltic Sea has been an important region for bioenergy *trade* since the 1990's. Both unrefined wood fuels – such as wood chips – and densified fuels – e.g. wood pellets – have been traded to large extents in the Baltic Sea. Trade between countries generally leads to integration of the markets of the countries and to price convergence, i.e. that the prices in trading regions will tend towards each other. Furthermore, if markets already are integrated, the prices in the different geographical regions should not differ by more than the cost of transport between the regions. In this study we assess the level of bioenergy market integration in the Baltic Sea by studying the development of wood fuel prices over time in three Baltic Sea countries: Estonia, Finland and Sweden. The empirical analysis has been conducted by time series analysis using quarterly data from 1998Q1[18] to 2009Q3. Transport costs between the countries have also been accounted for by use of data on freight rates on Baltic Sea bioenergy transport in 2009Q3. These data have been combined with fluctuations in an index for freight rates and fuel prices during the time period in order to obtain a proxy of the transport cost development. In Figures 5-7 a graphical presentation of the developments in prices and transport costs can be seen. Note that Estonia is in all cases seen as the exporting country and Sweden is seen as an importer in all cases whereas Finland is seen as an importer vis-à-vis Estonia and an exporter vis-à-vis Sweden.

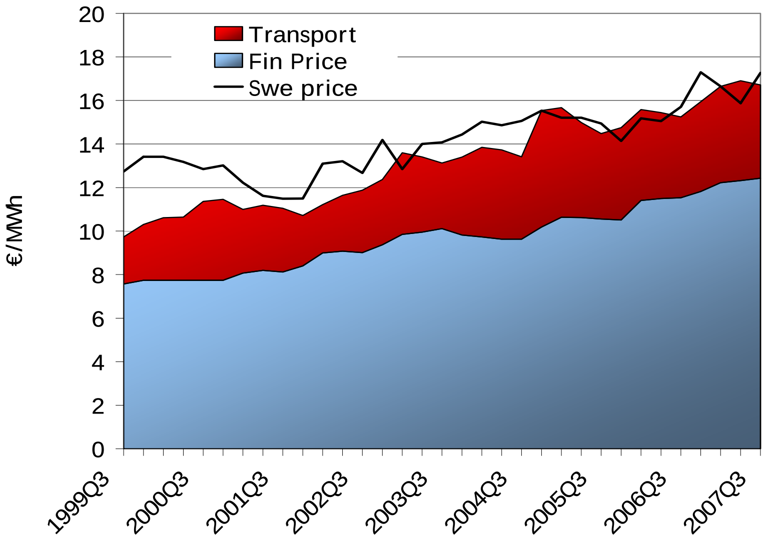

Figure 4. Development in Swedish and Finnish wood fuel prices as well as estimated developments in transportation costs from Finland to Sweden 1999Q3-2007Q3. Source: Statistics Finland (2009); Swedish Energy Agency (2009) and own calculations.

[18] i.e. the first quarter of 1998

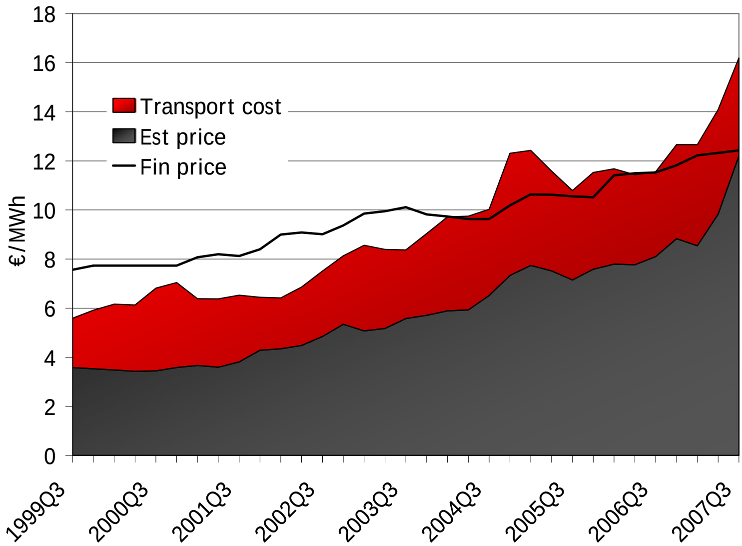

Figure 6. Development in Finnish and Estonian wood fuel prices, as well as estimated developments in costs of transportation from Estonia to Finland 1999Q3-2007Q3. Source: (Metla 2009; Statistics Finland 2009) and own calculations.

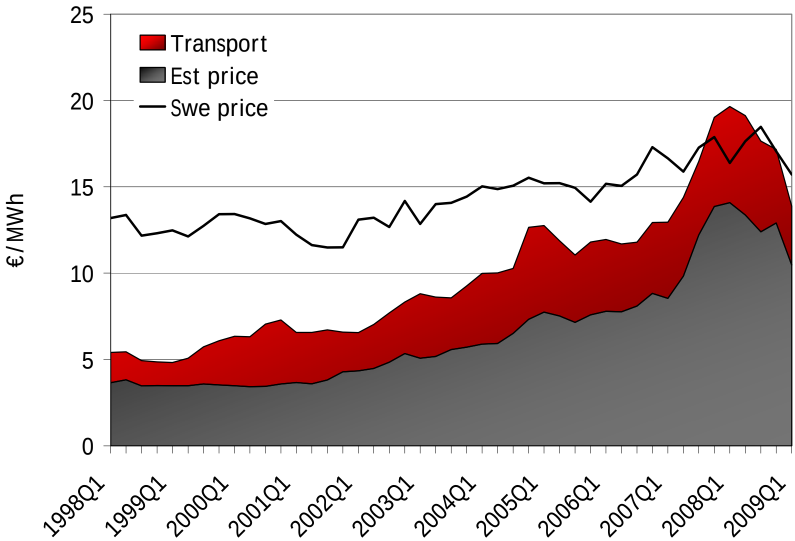

Figure 7. Development in Swedish and Estonian wood fuel prices, as well as estimated developments in costs of transportation from Estonia to Sweden 1998Q1-2009Q1. Source: (Swedish Energy Agency 2009; Metla 2009) and own calculations.

3.2.2 Paper II: Main findings

From the results of the time series analysis tests performed in this study, we may conclude that there is no short-run convergence between the prices of wood fuel in the three countries studied. We find no evidence of cointegration between any of the price series, regardless of whether transport costs are included or not. However, the spread in price levels has decreased substantially over the time period. Although this is in large part due to a more rapid pace of economic growth and inflation in Estonia than in Sweden and Finland, we find that even with inflation-adjusted prices, price convergence has occurred. This result is similar to what has been found in studies of Baltic Sea markets for other forest products (Toppinen et al. 2004; Toppinen et al. 2005;).

3.2.3 Paper II: Discussion

Although there is not yet any evidence that point to an integrated market for wood fuels in the Baltic Sea, the slowly converging prices between Estonia, Finland and Sweden indicate this may not lie to far ahead in the future. Yet, it is important to remember that due to data constraints, this study has only focused on three of the nine countries that line the Baltic Sea. Excluded are both countries that are projected to be future large net importers of wood fuels, like Denmark and Germany, as well as countries like Russia that have unutilized biomass resources. Hence, this study paints only part of the picture that is the Baltic Sea wood energy market. As more price information gradually becomes available and the market becomes increasingly transparent, future studies into the area will be able to complement the results herein.

Generally, we may expect wood fuel trade in the Baltic Sea to increase given the large resources and the large potential consumption in the area. However, a factor that must be taken into account is the development of transport costs. Although the transport costs in this study are only estimations, the resulting figures point to the increased costs of transportation – along with the general price convergence in the wood fuels - as one possible contribution to the decrease in Estonian-Swedish wood fuel trade that can be seen from 2003 to 2008. As the difference in prices between the two countries have narrowed as transportation costs have increased, arbitrage opportunities for Swedish buyers have largely disappeared.

4 Discussion

The purpose of this thesis - as stated in section 1.4 - is to assess the degree of bioenergy market integration between European countries. As the results from the two studies included in this thesis show, Europe still has a long way to go before it is possible to speak of a common European market for bioenergy. Only in one case – the Austrian/German market for residential market wood pellets – there were signs of international market integration. Hence, there is not yet a "European price" for wood pellets (Dahl 2005), although the close price connections between Germany and Austria certainly indicate that international wood pellet market integration is certainly taking place to some degree. In the large scale market, there were no signs of market integration between the three countries studied. This shows that fragmentation and lack of market integration is not only a issue in EU markets for e.g. natural gas and forest products markets, but for bioenergy as well. However, the *reasons* for the lack of market integration in bioenergy are connected to the specific properties of the bioenergy sector. Bioenergy markets in general are still immature and rather undeveloped and there are still market barriers in the form of standardisation issues, logistics and not least information transparency.

The latter issue also presents an obstacle when attempting to analyze the lack of market integration and price convergence in the European bioenergy market. Specifically, the lack of detailed and reliable trade data means that it is difficult to go deeper into the causes for market integration and assess whether the lack of price convergence indeed is due to low levels of trade or if there are price dispersions despite active international trade. In the wood pellet market, which was the focus in **Paper I,** information on trade flows has increased drastically from 2009 with the introduction of a customs code for wood pellets. This enables future studies of the continuing development of wood pellet markets to obtain a more comprehensive view of wood pellet markets through studies of the interaction between prices in different countries and corresponding trade flows.

However, assuming that the lack of price convergence indeed is due to a lack of trade in wood pellets between Sweden and the continent, there are several reasons for why this might be the case. To begin with, Sweden is not a member of the European Monetary Union (EMU). This means that traders aiming to take advantages of the price differences between Sweden and Germany/Austria have to be prepared to accept the risk of exchange rate fluctuations between the SEK and the Euro, which may affect the profitability of trade in either direction. Furthermore, the major part of the German wood pellet industry is located in the South of the country - close to Austria - which might have favoured market integration with Austria rather than Sweden. Finally, the cultural and linguistic ties between Germany and Austria should not be underestimated.

In the large scale market - which was in focus in **Paper II** - ship transport is by far the most economical mode of transport. This is an important reason for the significant trade in solid biofuels in the Baltic Sea and the gradual market integration that has followed. Ship transport enables trade of even low-energy density fuels - such as wood chips - across distances where road transport would be out of the question. However, the high levels of sulphur in the bunker fuel used for ships could be a problem for the continuing expansion of bioenergy trade by sea. In late 2008, the International Maritime Organization (IMO) decided upon higher environmental standards for maritime fuels that will be gradually introduced in the coming decade and that aim to decrease SO_x emissions from ships (IMO.org 2008). The Baltic Sea is one of the IMO Sulphur Emission Control Areas (SECA) which means that especially strict standards will be introduced. According to these regulations, there will be a limit of no more than 0.1% sulphur in maritime fuels used in the Baltic Sea from 2015. According to the Swedish Maritime Administration, this is likely to bring about an increase in shipping costs of 20-28%. (Swedish Maritime Administration 2009) This could be an important factor for the continuing profitability of bioenergy trade in the Baltic Sea.

Comparing the level of market integration in the wood fuel market to other forest product markets of the Baltic Sea region - discussed in section 2.2.2 - we see that the wood fuel markets are not unique in the lack of market integration. It seems that in North European forest product markets, market segmentation between countries is still more common than market integration. Since wood fuels generally have a lower value than pulpwood and saw timber – and hence are more sensitive to transportation costs – it may not come as a surprise that this holds true also for wood fuel markets.

Conclusively, it can be said that although the understanding of how bioenergy markets function is increasing through improved market transparency, there are still plenty of holes to be filled. Research into the price mechanisms of the bioenergy markets is one particular field that is currently underdeveloped. Although this thesis has hopefully made some contribution to the knowledge about the relationships between national prices, other phenomena affecting bioenergy prices have only been scarcely investigated. The impact of transport costs has been touched upon in this thesis, but there are certainly a lot of questions that remain unanswered. Furthermore, the use of new raw materials for wood pellet production is one factor that could have an important impact on the long-term development of pellet prices. Another issue is if and how the expected increase in bioenergy imports from other continents will affect bioenergy prices in Europe.

Given the fast growth in bioenergy markets that is expected in coming years, it is important that more studies of bioenergy markets are conducted. All over Europe, large amounts of capital are currently being invested into facilities for energy conversion based on solid biofuels (see e.g. Argus Media 2009). This is quite remarkable, given that there is still a general lack of understanding of how the bioenergy markets function and will function in the future. Bioenergy holds great promises and trade can be an important tool to ensure efficient implementation, but in order to minimize environmental as well as economical risks, European bioenergy market actors should be advised to look before they leap.

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