



Horizontal price transmission in dairy markets: Finland and major trading partners within the EU

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Tiivistelmä – Referat – Abstract <p>The dairy sector in Finland and the EU has experienced several important shocks during the past decade, causing increased instability and dramatic price movements. It has put pressure on different market participants as well as on policy makers while simultaneously driving a growing interest for price transmission studies. However, gaps in the research field persists and this study addresses this void by focusing on the characteristic of Finnish raw milk prices and their relation to the prices of key trading partners, including Sweden, Denmark, Estonia, Germany and France. Considering descriptive statistics and graphical representations, the assumption that Finnish milk prices exhibit relative independence seems plausible. This seemingly independent behavior challenges theoretical foundations related to market equilibrium while prompting questions about market efficiency</p> <p>Employing econometric time series analysis, this study covers the 2013-2023 timeframe and pursues two main objectives: identifying a potential long-run cointegration relationship and studying short-run impacts of other countries' milk prices on Finnish prices. The Engle-Granger two-step framework is used for the cointegration analysis, confirming the hypothesis that Finnish milk prices operate autonomously, lacking a long-run equilibrium with other EU countries. Although some previous papers suggests that milk prices in the EU generally seem interconnected, Finland has not been the focus of such studies. The finding of this paper aligns with literature suggesting weaker cointegration in dairy markets compared to other agricultural sectors in the EU.</p> <p>The paper discusses potential explanations, considering structural characteristics of the dairy sector, dairy trade features, and broader market inefficiencies influencing price transmission. However, additional research is warranted to comprehend practical implications, particularly concerning market efficiency and the competitive status of participants in the domestic dairy sector.</p> <p>Short-run influences are modeled by applying a dynamic ordinary least squares regression with lagged price variables. The outcomes reveal rather unexpected results, with main trading partners such as Sweden, Denmark, and Germany, exerting no significant influence on Finnish prices. In contrast, France and Estonia seem to exhibit considerable influence on Finnish milk prices. Caution is advised in interpreting the short-run impacts, addressing the possible shortcomings of such regression for example regarding potential arbitrariness in the indications of the model.</p> <p>Ultimately, the results of this study point at some general implications, suggesting that price transmission is not solely a consequence of physical trade, and that the intricate characteristics of the dairy sector clearly challenge the direct application of economic theories like the law of one price to agricultural commodities. The need for a nuanced understanding of price dynamics in the dairy market is underscored as an important element of policy and market efficiency considerations.</p>			
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1 Introduction

Milk production in Finland has a long history and the dairy sector is certainly one of the cornerstones of agriculture and of the food industry as a whole. In absolute terms, Finnish milk production only represents two percent of total production in the EU, but per capita production of raw milk is among the highest in Europe. The Finnish dairy industry is known for its high quality standards, innovative product development and sustainability values. In addition, trade balance is positive and trade is crucial for the dairy sector and the economy as a whole.

During the past decades, the dairy sector has been subject to several extensive market shocks, including the financial crises in 2007-2009 and 2014-2016, the Russian embargo in 2014 (affecting Finnish dairy exports in particular), the abolition of EU milk quotas in 2015 as well as recent years of turmoil, with a global pandemic followed by war in Ukraine and high inflation. These events have caused instability and dramatic price movements on the commodity markets, not leaving the dairy industry unaffected. Increasing volatility and uncertainty have placed growing pressure on the sector and also been driving forces in the large-scale structural development that has taken place since the beginning of the century. The need of understanding more complex price linkages in agricultural commodity markets have been unveiled, and as a consequence, research on horizontal price transmission has experienced an upswing (e.g., Listorti and Eposti, 2012; Bórawski et al. 2020).

Horizontal price transmission commonly refers to the price relationship of homogenous goods at the same position of the supply chain in spatially separate markets (e.g., Listorti and Eposti, 2012). From a Finnish perspective, as a country in the outskirts of Europe, pricing and efficiency are essential issues when considering the competitiveness and prospective of the industry. The Finnish dairy sector and food retail are highly concentrated. Thus, information on spatial price adjustments and market efficiency is important not only for market participants and when considering competition strategy, but also for policy makers when regulating the sector (Liu, 2011). Finnish consumers have traditionally had a strong demand for Finnish-origin milk and fresh products, but this situation is at risk of changing as the demand for imported goods, especially processed products such as cheese and yoghurts has grown steadily (Rezitis, 2018). In addition, recent years with dramatically increasing food prices have driven a change in consumers' behavior as people seek for cheaper alternatives.

A key question of this study relates to the Finnish milk prices and their relation to other EU countries. Finnish raw milk prices tend to sit higher than the EU average, with only a few exceptions throughout its history as part of the Union. Meanwhile, the closest neighbor Estonia show significantly lower average prices and major milk producers such as Germany and France have prices close to the

European mean. During times of volatility, Finnish milk prices have shown more moderate movements compared to other European countries, both in terms of speed and magnitude. These observations certainly raise questions as to what extent Finnish milk prices are cointegrated with other European markets, provided the alternative hypothesis that the Finnish dairy market would perform independently. However, while visual examination of graphs is only a starting point, statistical evidence is needed in order to confirm this hypothesis. Although economic theory suggests equalization of prices in efficient markets, these models may not be applicable to the dairy markets for several reasons (e.g., Vargova and Rajcaniova, 2018; Arovuori et al. 2019; Bakucs et al. 2019; Hamulczuk, 2020; Jurkenaite and Mikelionyte, 2021). To recognize why, it is important to understand the characteristics of the dairy sector in terms of structure and how the markets are organized, discussed more in 2.4.

Price transmission analysis in agricultural markets is important for multiple reasons. In addition to providing valuable insights when assessing the efficiency and competitiveness of the markets, it is useful for policymakers in order to make informed decisions when designing and implementing new policy measures related to trade, production or other areas, both at the domestic and EU level (Rezitis, 2018; Vargova and Rajcaniova, 2018; Jurkenaite and Mikelionyte, 2021). Price transmission is desired for markets to be efficient, and since efficient markets is a major objective of the EU, understanding these dynamics is crucial for the Union as a whole (Liu, 2011).

Although horizontal price transmission has gained increased attraction, literature focusing on the European dairy market is still scarce (Jurkenaite and Mikelionyte, 2021). Considering the Nordic countries, the research gap is even wider. For the present, there is no study focusing on horizontal price transmission in the Finnish dairy sector in particular. This paper aims to help fill this research gap by exploring price linkages between Finland and five European dairy markets, including Sweden, Estonia and Denmark, as well as Germany and France.

The main objective with this paper is to characterize price transmission between Finnish milk prices and the ones of selected countries, also major trading partners in terms of dairy. An important research question to answer is whether Finnish milk prices are cointegrated with the ones of other markets. That is, are prices linked by an equilibrium relationship in the long-run. If cointegration is established, the elasticities of price transmission can be quantified to describe to what extent and how fast prices and price shocks are transmitted, i.e., how short-run prices adjustments are consistent with the long-run equilibrium. In addition, the study aims to describe short-run dynamics and the potential impacts other markets may induce on Finnish milk prices. Thus, to some degree, the efficiency of the Finnish

dairy market is evaluated and further, implications of the price transmission analysis are linked to underlying economic theory, while also considering the characteristics of dairy markets.

The econometric analysis comprises unit root tests to determine stationarity conditions of the data, followed by a cointegration analysis to assess a potential long-run relationship. Cointegration is examined using the Engle-Granger framework with associated linear regression methods. If cointegration is found, an error correction model (ECM) is estimated to assess the speed and magnitude of price transmission. If cointegration is not established, short-run price movements are studied by adopting dynamic ordinary least squares regression. The qualitative part of the study focuses on presenting some economic theory regarding price transmission and related concepts, as well as discussing main features of the Finnish and European dairy sector.

The paper is organized as follows: *section one* introduces the main topic and objectives. It also comprises a brief review on previous price transmission literature. *Section two* aims to describe the Finnish and EU dairy sector, including features related to market structure, production and trade. *Section three* presents some more in-depth definitions and concepts along with theory relevant for the study. In addition, some general inefficiencies related to dairy markets are discussed. *Section four* is devoted to considering the properties of time series analysis as well as presenting the empirical methodology and data of the study, while *section five* presents the results of the econometric analysis. *Section six* then covers some further discussion and *section seven* final conclusions.

1.1 Previous literature on price transmission

Price transmission studies have been carried out increasingly on EU dairy markets, and although the largest share of studies focus on vertical price transmission (e.g., Serra and Goodwin, 2003; Falkowski, 2010; Weldesenbet, 2013; Dudová and Bečvářová, 2015; Rezitis, 2018; Antonioli et al., 2019), research on horizontal price transmission has gained increased attraction. However, literature varies in terms of geographical coverage. Some studies focus on price transmission between different locations in one country, some examine selected groups of countries, and others are EU-wide in coverage. Further, studies vary with regard to methodological framework, data frequency, periods of investigation, inter alia (Jurkenaite and Mikelionyte, 2021). The heterogeneity in terms of methodologies and data combined with the relative scarce amount of studies makes it difficult to generalize the results of existing research (Bakucs et al. 2019; Hamulczuk, 2020). Popular methodologies in time series analysis are the Engle-Granger two-step method and the Johansen procedure for assessing cointegration relations (Jurkenaite, and Mikelionyte, 2021).

On a wider scope, Listorti and Eposti (2012), Vasciaveo et al. (2013) and Hamuleczuk (2020) among others have done some effort on discussing fundamentals of horizontal price transmission in agricultural commodity markets as well as methodological issues related to existing research. This sort of literature is important for understanding theoretical concepts, the strengths and shortcomings of research methods and for the development of existing and new approaches.

Holst and von Cramon-Taubadel (2013) look at horizontal price transmission in EU pork markets, while Vermeulen and Peersman (2016) analyzes European grain markets. Important contributions to the literature on horizontal price transmission in Finnish commodity markets include Xing Liu (2011), who uses the Johansen framework to examine price cointegration between Finnish meat markets and those of Denmark and Germany. Rezitis (2018) is another significant contribution in a Finnish context, analyzing vertical price transmission in the domestic dairy sector.

Important studies regarding the European dairy sector include Katrakilidis (2008), Vargova and Rajcaniova (2018), Bakucs et al. (2019), Roman (2020) and Jurkenaite and Mikelionyte (2021). Katrakilidis (2008) studies long-run linkages of milk prices in France, Germany, Denmark, Netherlands, and Belgium. Vargova and Rajcaniova (2018) target the Visegrad countries (Slovakia, Czech Republic, Poland, and Hungary). By employing vector error correction models, both studies find long-run price associations, implying that milk prices in these countries seem to co-move and influence each other. They conclude that EU dairy markets seem strongly interdependent.

Using Granger Causality methodology, Jurkenaite and Mikelionyte (2021) examine short term price movements of raw milk in selected EU countries (Germany, France, the Netherlands, Poland, Lithuania, and Latvia), finding that prices of the older member states have a stronger interrelation when compared to the countries that joined the EU in 2004. However, younger member states show signs of significant improvement when comparing to the early post-accession period.

Bakucs et al. (2019) challenge the above conclusions of highly interdependent dairy markets in a study comprising 20 of EU's member states (98 % of EU milk production). In terms of methodology, their study is similar to this, although more extensive in coverage. Cointegration and the law of one price are tested using the Engle Granger framework, and their findings suggest cointegration of milk prices is significantly less prominent than that of other agricultural sectors, such as meat (Holst and von Cramon-Taubadel, 2013). It is well known that dairy markets differ from other commodity markets in how they are organized in space, and this is believed to influence how prices form and adjust. Bakucs et al. (2019) also find evidence of cointegration between countries not engaged in trade, supporting the hypothesis that price transmission does not require physical trade.

2 Dairy markets in Finland and the EU

2.1 Finnish dairy sector

Milk farming is undoubtedly a cornerstone in Finnish agriculture. This is understandable, since milk production has a long history and is the only agricultural activity that can be practiced in any part of the country. Further, it is the single most important sector of the Finnish food industry, and the considerable set of added-value products developed by the industry is the only food product group with a persistent positive trade balance ever since the accession into the EU (Rezitis, 2018). In addition, consumer demand for domestic milk products is generally strong, especially regarding fresh milk products. However, importers have gained growing shares of the increasing demand of processed products such as cheese, posing a threat towards domestic markets (Jansik et al., 2014). Past years with high inflation and rising food prices has further promoted this development. According to a recently published PTT report ([Ruokaketju](#), 2023), price awareness has increased significantly during the past two years, as consumers are seeking for more affordable alternatives at the cost of preferences related to product origin or climate and health impacts. The study shows that 30 % of consumers have purchased more foreign food products during the last two years due to their affordability. Further, less than a third of young people announce that domesticity is the most important determinant of a purchase decision, compared to 65 % among elderly people. Although it is too early to tell how permanent these changes are and to what extent trends may revert as consumers gain back lost purchasing power, it is evident, that the domestic dairy sector is facing new challenges. In light of this rapidly changing market environment, price transmission analysis has become an increasingly important research field.

2.1.1 Structural change

Subsequent market shocks, changes in the EU policy framework and technological development are some of the main forces that have driven the structural change in the Finnish dairy sector throughout the past decades as well as a similar development across the European Union. The long-term structural change has implied a substantial decrease in the number of farms and dairy cows, as well as an increase in herd size and average milk yield per cow. The number of Finnish milk farms have declined from well over 22 000 in the beginning of the century to less than 4 400 in 2023 (see Figure 1), and the number of dairy cows has decreased by a third, to around 248 000 in 2023 ([Luke Statistics database](#)). At the same time, average herd size has more than doubled from just below 20 to over 56 cows per farm, and average milk yield per cow has exceeded 10 000 kg/year, compared to 8000

kg/year in 2002 (ProAgria, 2023). While technological development and a shift towards bigger production units have offered means to improve efficiency and profitability for progressive farmers, others may be trapped in what economic theory describes as the agricultural treadmill (e.g., Hansen, 2019). According to Hiironen et al. (2016), growing farm size has not resulted in increased profitability as expected. Acquisition of farmland often results in increasing distance between field parcels and farm compounds. Thus, improvements in farming profitability is prevented partly by the additional costs related to property fragmentation.

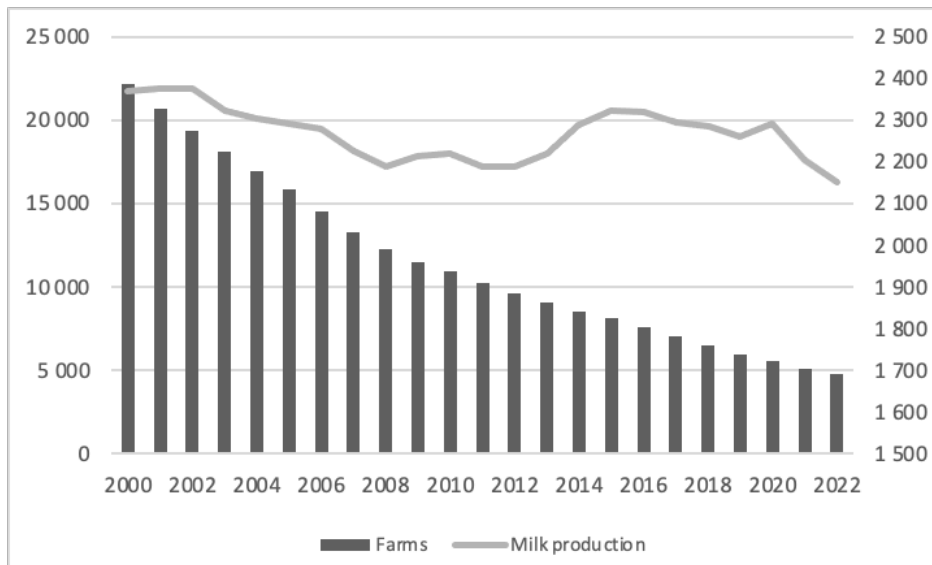


Fig. 1. Finnish dairy farms (left axis) and total raw milk production (right axis) in millions of liters. Source: Luke Statistics database.

Although the total production volume of milk has been trending downward in recent years, milk production in Finland has remained relatively constant throughout the decades (see Figure 1). In global milk markets, declining production volumes is a rare situation, where both demand and production volumes normally increase year-on-year, and thus, price balance depends on which grows faster. In Finland, milk production has been affected by similar factors like the global market in terms of rapidly rising energy and feed prices. This has clearly impacted milk prices and production levels, although the effects have been more dramatic in other regions. Domestic milk consumption has been decreasing for several years already, and contractual production adopted by Valio Group, in which price steering aims to control production volumes, has contributed to controlling the average output in line with demand. Balance between supply and demand naturally affects prices and thus, it may in part explain why domestic milk prices have been relatively stable when compared to many other European member states (Latvala et al. 2022).

2.1.2 Market dominance

The Finnish dairy industry is characterized by a cooperative ownership with only a few large dairy companies dominating the market. According to a report by Jansik et al. (2014), the concentration ratio (CR4) with respect to sales revenue was 88 % in 2012, and the situation is unlikely to have changed significantly. Valio Group is the leading dairy processing company, collecting around 85 % of the Finnish raw milk, and Danish registered Arla Foods its most important competitor. According to Rezitis (2018), it is plausible, that the dominance of a few companies in the fresh milk market and the high concentration ratio in processing and sales affect the way prices are formed on the Finnish dairy market. In 2012, Valio Group was fined by the Finnish Competition and Consumer Authority, FCCA, due to its dominant position. It was stated that the company was setting the price of raw milk during the period 2010-2012 and using predatory pricing against its competitors.

Although this highly concentrated nature of the Finnish dairy supply chain may be of particular interest when studying price transmission inside the supply chain (i.e., vertically), it is of importance also when analyzing horizontal price transmission. High market concentration and cooperative ownership of big dairy companies may have significant impacts on market efficiency. Thus, it is assumed to explain at least in part why Finland show higher milk prices than the EU mean (Rezitis, 2018). On the other hand, German milk prices are generally close to the EU average due to the size of its milk production, resulting in a direct influence on the EU milk prices. However, while these deviations in price levels might seem intuitive when visually evaluated, econometric time series analysis is needed for drawing any conclusions. Hence, while graphs are a good starting point, only statistical tests can provide evidence of actual price dynamics.

2.1.3 Trade

An essential feature of dairy markets in general is the degree intra-industry trade, referring to trade of similar goods that are part of the same industry. As an important concept in international trade theory, it is closely linked to the idea of comparative advantage, which has been used in models of trade by famous economists such as David Ricardo in order to explain why countries trade. The intuition is that intra-industry trade allows countries that can produce similar goods to specialize where they have a comparative advantage, essentially implying a lower opportunity cost for producing a good. Hence, it allows for economics of scale, encourages to competition, and eventually drives innovation and product development further (Krugman et al. 2015). The concept of comparative advantage becomes clearer when examining the trade structure of Finnish dairy exports

and imports, presented in Figure 2. It is evident that, although trade occurs in both directions, product groups vary depending on which direction they are traded. With other words, Finland does not generally import the same goods as it exports, and vice versa.

While foreign trade is important for the Finnish food industry as a whole, the dairy sector constitutes the single most important product group, accounting for a 21 % share of food exports in 2022 (Luke [Statistics](#)). Despite important market shocks, such as the Russian import ban in 2014, trade balance for dairy products has remained positive throughout the EU membership period. In 2013, trade surplus peaked at approximately 162 million euros, but eventually dropped to around 13.5 million euros in 2016 following the Russian sanctions (Arovuori et al. 2019). Although the industry has largely recovered, and trade surplus amounted to 70 million euros in 2022, the path to recovery has not been a straight line and has required substantial rearrangements both in trade patterns and in the structure of exports. In other words, a significant change has occurred both in terms of which markets Finland trade with, as well as what dairy products are traded. In 2013, Finnish dairy exports to Russia amounted to almost 252 million euros, about 50 % of total exports, but fell rapidly below 5 million euros post 2014. Due to further complications regarding the war in Ukraine, exports to Russia were close to zero in 2022. Instead, trade with EU-members has increased over the past decade, and especially exports to Sweden, France and the Netherlands have grown significantly. Further, new trade relations have developed mainly in Asia, with China as a significant and continuously growing export market (Arovuori et al. 2019).

Table 1 shows Finland's ten largest EU trading partners in 2022. Export and import values are presented separately, as well as the proportions of total value. Although EU is certainly the main market both for dairy exports and imports, Finland has a significant export market outside the EU as well, with more than 215 million worth of exports, or 38 %, traded outside the EU. More than half of that, or 128 million euros, stem from exports to China while other important markets include the United States, Malesia and Singapore. Within the EU, major export markets include Sweden, France, the Netherlands and Belgium, with Sweden accounting for 25 % of Finnish dairy exports alone (Finnish Customs, [Uljas](#)). Furthermore, Estonia, Germany and Denmark also fit in the top ten, both in terms of exports and imports. In contrast to exports, almost 99 % of Finnish dairy imports originate from within the EU, with the most important trading partners being Germany, Denmark and Sweden, together accounting for nearly 50 % of Finland's imported dairy products. The important trade relations between Finland and these particular countries is a key motivation to the inclusion of them in this price transmission study.

Table 1. Finland's major intra-EU trading partners, dairy products. Value of 2022 exports and imports and percentage shares of total dairy trade. Source: Own calculations based on data from [Uljas](#) statistical database, Finnish Customs

Country	Export value (1000€)	%	Country	Import value (1000€)	%
Total	568 014*	100,0 %	Total	474 665*	100,0 %
EU	352 346	62,0 %	EU	468 237	98,6 %
External trade	215 668	38,0 %	External trade	6 429	1,4 %
Sweden	142 093	25,0 %	Germany	118 278	24,9 %
France	67 321	11,9 %	Denmark	100 403	21,2 %
Netherlands	33 528	5,9 %	Sweden	53 729	11,3 %
Belgium	24 067	4,2 %	Netherlands	44 265	9,3 %
Estonia	17 248	3,0 %	Estonia	38 674	8,1 %
Germany	14 000	2,5 %	Italy	24 634	5,2 %
Poland	13 729	2,4 %	Belgium	17 557	3,7 %
Denmark	11 468	2,0 %	France	16 194	3,4 %
Italy	10 071	1,8 %	Poland	10 790	2,3 %
Ireland	5 074	0,9 %	Austria	9 780	2,1 %
Top 10	338 599	59,6 %	Top 10	434 304	91,5 %

*includes eggs and egg-albumin with tot. exports accounting for ca. 30.5 mil. € and tot. imports ca. 7.7 mil. €

A closer look at Figure 2 allows us to observe that, in terms of exports, the product range is wide and export shares relatively evenly spread although butter and condensed milk products stand out as the two largest product groups. High level of product differentiation signals that the dairy sector, and milk production in general, is a productive and important industry in Finland. It is sensible, considering the long history of milk production in Finland, and further in line with the positive trade balance. Nevertheless, not all products can or should be produced domestically, and consequently Finland also need to import some dairy products. In terms of imports, the dominant product group is cheese, with more than a 70 % share of total imports in 2022, followed by 24 % for yoghurts, curdled milk, buttermilk etc. All other products are imported only marginally. Considering the increasing demand for cheese on global markets, this consumer trend is also evident among Finnish consumers, and cheese imports have been growing steadily throughout the 21st century (Arovuori et al. 2019). Presumably, import demand for cheese can be explained to some extent by the high degree of product differentiation characterizing the product group, considering that trade with cheese often is tied to a specific country of origin. Thus, although consumer demand for domestic dairy products is generally high in Finland, the cheese sector faces a challenging situation with respect to competition.

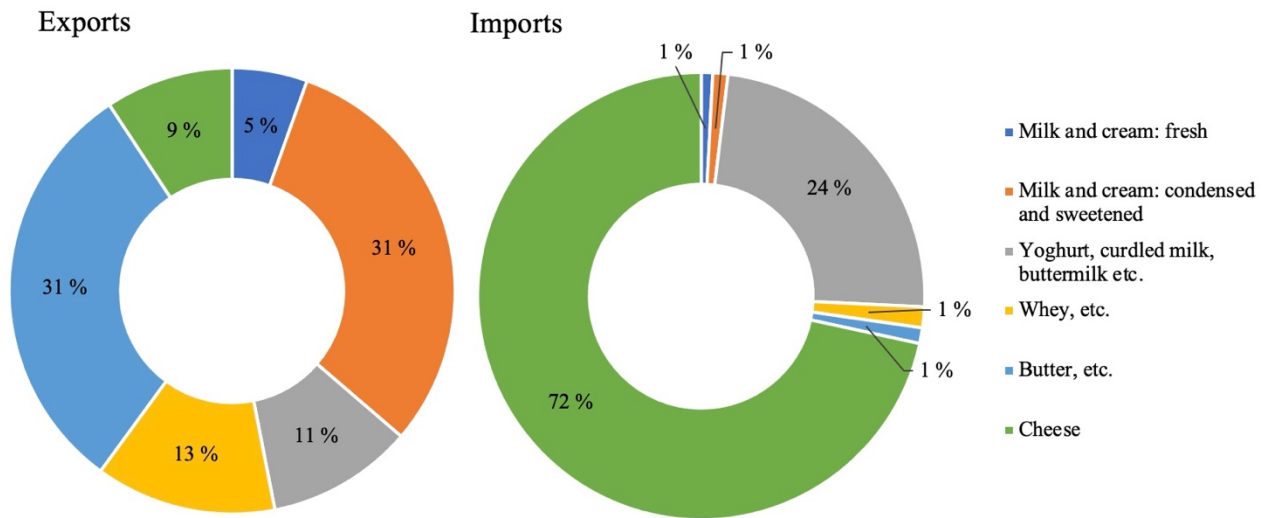


Fig 2. Dairy trade structure presenting export and import product groups respectively, measured in percent shares of value in euro. Source: own generations based on data from Finnish Customs, [Uljas](#) Statistical database

The Russian embargo in 2014 denoted a critical turning point not only for trade patterns of Finnish dairy trade, but also for the trade structure. Significant shifts were seen particularly in the structure of exported product groups, such as in cheese. After having accounted for more than 40 % of Finnish dairy exports, this share rapidly fell as Russian imports ceased. It is evident, that new markets have not yet been discovered for the Finnish cheese, as it only accounted for 9 % of exports in 2022. On the other hand, butter has become a major export product, accounting for more than 30 % of exports in 2022. Similarly, milk powder exports have been growing rapidly, from a 5 % share in 2008 to more than 30 % of exports in 2022. However, when compared to more processed and added-value goods such as cheese, milk powder and whey are bulky products and their prices on the export market are determined by global demand and supply conditions. In addition, since it is a long lasting product, milk powder is generally produced when there is a surplus of milk on the market, resulting in excess supply and falling prices. Hence, although Finnish milk powder exports have increased significantly over the years, prices on the export markets have decreased substantially and profitability of milk powder export is poor in comparison with other product groups (Arovuori et al. 2019). Nevertheless, with respect to global competition, Finnish dairy industry has shown signs of being highly competitive by bringing innovative and sustainable products to the market. In addition, domestic dairy products are generally known for being of high quality, safe, free from antibiotics residue, non GMO and traceable to their origin ([Valio](#), 2023). All these features are likely to affect consumers' preferences and may explain in part why Finns are ready to pay more for domestic produce. Consequently, this gives the domestic dairy sector a competitive advantage over imported goods, despite higher production costs in Finland.

Ultimately, although the Finnish dairy market may seem integrated with other EU markets when considering the extensive trade flows, price transmission and market efficiency are separate topics (the implications and distinction of these concepts are further discussed in section 3.2). It is well known that perfect price transmission is unrealistic for several reasons (section 3.3. and 3.4.), particularly in agricultural commodity markets (Vargova and Rajcaniova, 2018), and for a small open economy like Finland even more. Also, due to substantially higher production costs, Finnish costs cannot be integrated with the competitive production cost and product prices in other parts of Europe (Liu, 2008). While the main intention of this study is to analyze transmission of milk prices and consequently evaluate market efficiency, it is of relevance to also consider the trade relations between the countries while linking them to the outcome of the econometric analysis.

2.2 EU dairy sector

Throughout its history, the EU dairy sector has experienced a continuous evolution and has been shaped by policies, market shocks and globalization. However, considering how industry- and service-oriented as well as how technologically developed Europe is today, agriculture still remains an important part of the economy, absorbing a substantial slice of the EU budget and contributing to a significant part of the economic output.

2.2.1 Production

Representing more than 12 % of agricultural output, the dairy sector is the second largest agricultural sector in the EU, only after the vegetable and horticultural plant sector ([EPRS](#)). Although all member states of the EU are involved in milk production in one way or another, a few countries account for a significant share of total output (Figure 3). Five main producers, including Germany, France, the Netherlands, Italy, and Poland together account for up to 60 % of total production, but on the other hand, smaller countries like Ireland, Denmark, the Baltic states, and Finland show higher production volume per capita, giving an idea of the significance of the dairy sector in these regions. Due to size, countries such as Germany may naturally have greater influence considering the price steering mechanisms on the European dairy market (Rezitis, 2018).

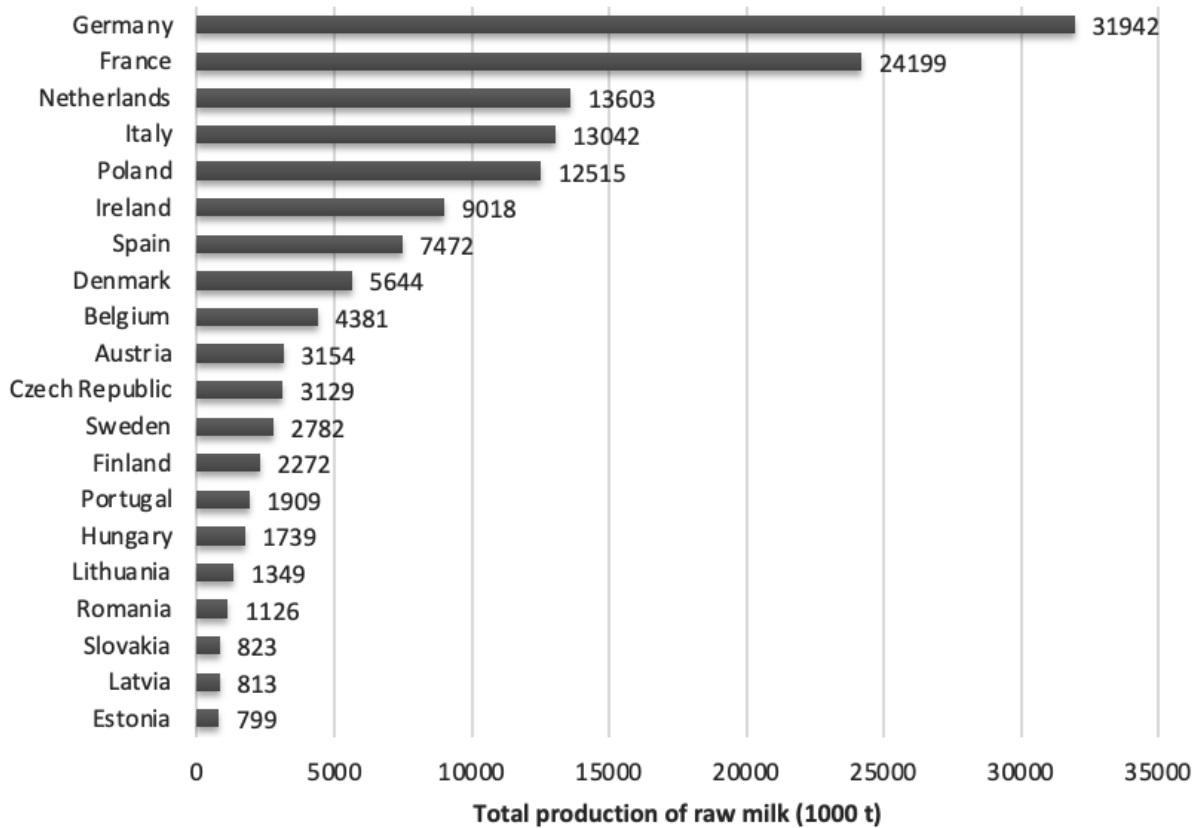


Fig. 3. Raw milk production in 2021, top 20 EU countries (1000 t). Source: Eurostat

In Europe, the dairy industry represents about 4 % of the whole food industry revenue, employs about 8 % of its workers and has a labor productivity of 53 000 EUR per worker. Furthermore, the dairy sector is considered the second most innovative business in the food industry, with a 6.9 % participation in food innovation in 2014 (Naglova et al. 2017). Thus, while it is obvious that the dairy industry is a critical part of the food industry in particular, the sector is certainly important for the economy of the EU as a whole.

2.2.2 Trade

With 144 million tonnes of raw cow's milk delivered to dairies in 2022, the EU27 is collectively the largest milk producer in the world as well as the second largest exporter of dairy products, only after New Zealand (e.g., Bórawski et al. 2020; [CLAL](#); [USDA](#)). Thus, in a global perspective, the EU is a significant player and, together with New Zealand and the United States, projected to account for around 65% of cheese, 68% of whole milk powder (WMP), 76% of butter, and 77% of skim milk powder (SMP) exports in 2029. Jointly about eight million tonnes of dairy products are annually exported from the EU. Main product categories include cheese, fat-filled milk powder (FFMP), bulk and packed milk as well as whey and SMP, see Figure 4 below ([CLAL](#)).

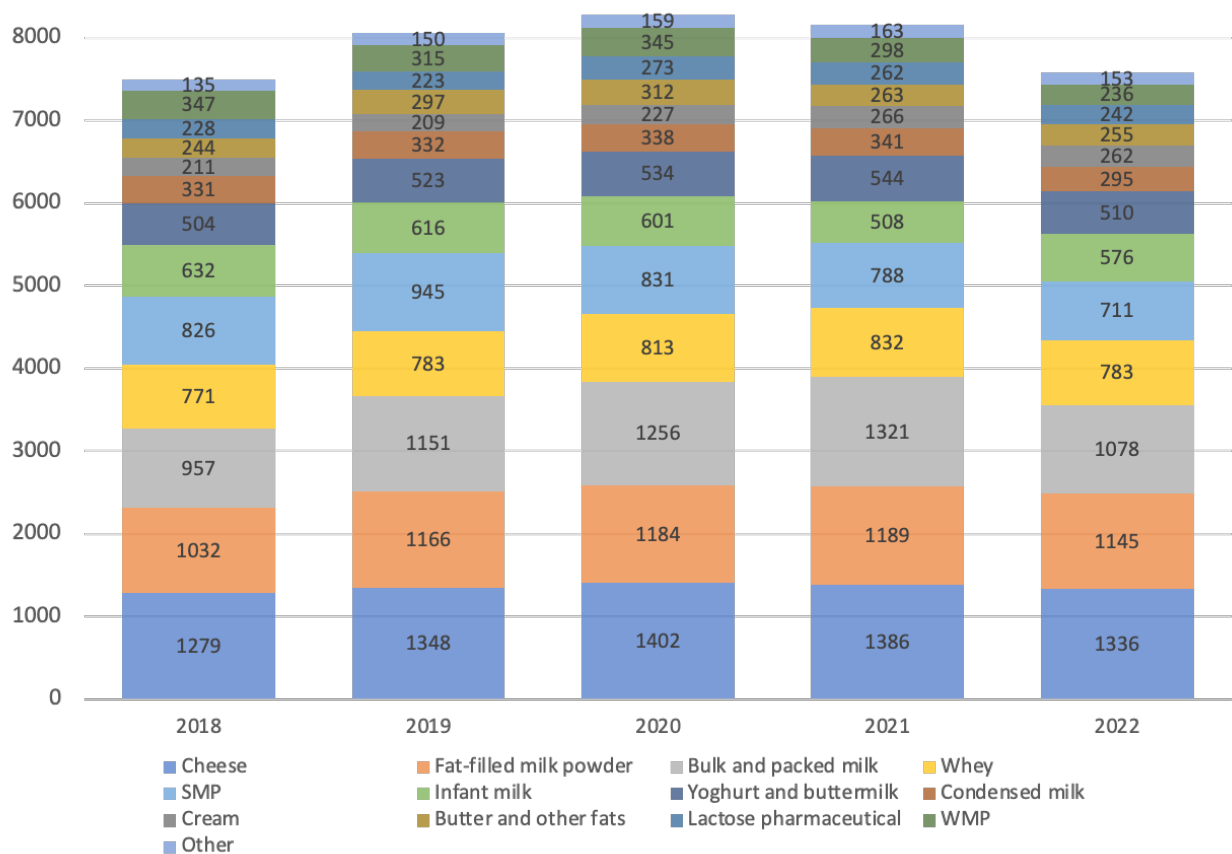


Fig. 4. EU-27 total dairy exports 2018-2022, main product groups. Source: Own elaboration based on data from Eurostat.

As a net exporter and with self-sufficiency levels of 112 % for butter, 114 % for cheese, 172 % for WMP and 215 % for SMP in 2022, the EU has a significant price dependency on export revenues and volumes on the world market. Main markets for European products include the Middle East and North Africa, but trade with Southeast Asia and China are also significant and is projected to grow in the future ([OECD-FAO](#)).

3 Theoretical concepts and definitions

3.1 Horizontal price transmission

As a concept, horizontal price transmission refers to the price linkages between different markets at the same position in the supply chain. For comparison, vertical price transmission refers to the price linkages along a certain supply chain, for example from producer prices to consumer prices. Generally, the concept of horizontal price transmission implies spatial price transmission, which refers to the process by which changes in prices for a particular commodity or service in one location affect prices of the same good in other locations over time. For example, the producer price of raw milk on the Finnish and German markets. Thus, it is the mechanism through which price signals are transmitted across geographical areas, allowing for convergence of prices and thereby for markets to be efficient (e.g., Listorti and Eposti, 2012; Vasciaveo et al., 2013; Bacuks et al., 2019).

Research on horizontal price transmission is useful when testing predictions of economic theory and provides insights as to which extent and how fast price changes in one market are transmitted to another, given that the markets are linked by a long-run relationship. Since efficient markets is a major objective of the European Union and its member states, the comprehension of these processes and linkages is crucial for policymakers to make informed decisions. In addition, market participants may be interested in the context of competition analysis, or when evaluating risk strategies (Liu, 2011; Rezitis, 2018). However, it is essential to understand that perfect transmission is not realistic and markets may be considered inefficient for many reasons, particularly in the dairy sector (Vargova and Rajcaniova, 2018), further discussed in section 3.4.

3.2 Market efficiency and market integration

The interpretation of market efficiency and market integration, as well as the role of price transmission in defining these concepts is not evident in the literature. Vague or inconsistent interpretations are rather common, for example using market integration and market efficiency interchangeably or referring to price transmission as a measure of market integration. While the two concepts might appear comparable, underlying mechanisms differ, as well as the way of measuring efficiency or integration. These terms are often used interchangeably because of the lack of comparable trade data (Vargova and Rajcaniova, 2018, Roman, 2020). In the interpretation of price transmission studies, it is often assumed that higher co-variability (co-movement) of prices in given markets reflects higher degree of market integration, although according to more precise definitions, price analysis alone cannot prove integration (Barrett and Li, 2002). However, since perfect price

transmission is commonly considered unrealistic, price transmission models are mostly used to describe how changes in supply or demand in one market transmits to another, and price transmission can, thus, reflect both the extent of market integration as well as the extent of market efficiency (Liu, 2008).

This study considers a more precise definition based on Barrett and Li (2002) and Holst and von Cramon-Taubadel (2013), who discuss the differences between market efficiency (as a consequence of price equilibrium in spatially different regions) and market integration (as a consequence of physical trade flows). The concept of market integration is linked to physical trade flows, implying that trade is desired for markets to be considered integrated. Meanwhile, market efficiency is linked to prices and their co-movement, implying that transmission of price information is desired. With other words, markets that pass price information quickly and fully can be considered efficient, although it does not express the level of market integration. Since the focus of this study is price analysis, the concept of market efficiency is naturally of higher relevance.

With respect to the above definition, one could different scenarios to be possible in agricultural commodity markets. First, markets may be integrated and efficient if both price information and physical goods move, a central objective for the European Union (Bórawski et al. 2020). On the other hand, if price transmission takes place but physical trade does not, markets may be considered efficient although not integrated. There is an abundance of evidence indicating that physical trade is not a requirement for prices to transmit (e.g. Stephens et al., 2012; Cramon-Taubadel, 2013), although it requires that prices are monitored by market participants and thus, transference of information is necessary (Bakucs et al. 2019; Hamulzuk, 2020).

Third, one can assume that markets are integrated although inefficient, implying that physical goods are traded, but prices do not move together, or transmission is slow and incomplete. With regard to this study it is perhaps the most interesting scenario, knowing that the selected countries are important trading partners. Finding no association or only weak transmission between Finnish milk prices and the other markets would be an interesting outcome. Section 3.4. and 4.7. will provide further insights in why this may not be a surprising outcome when considering the Finnish dairy market in particular.

3.3 Spatial arbitrage and law of one price

Two important theoretical concepts to understand when dealing with horizontal price transmission are spatial arbitrage and the law of one price (LOP), the first being the mechanism producing the second (Pippenger and Phillips (2008)). The act of arbitrage refers to the purchase and sale of

commodities in two or more spatially separate markets in order to make a profit from a price difference. Market theory suggests that, given homogenous goods and no trade barriers, the price difference between the goods will equal transfer costs (including loading, unloading, transport, information search, etc.) in markets that are engaged in trade. As long as the condition is not fulfilled, arbitrageurs will purchase products in the market where the price is lower and sell it where the price is higher in order to make a profit, thereby reducing the price differences to the level of the transfer costs. This is generally called the law of one price (Vasciaveo et al., 2013; Tomek and Kaiser 2014; Bacuks et al. 2019; Hamulczuk, 2020). Further, Tomek and Kaiser (2014) suggests a second principle for any two markets not engaged in trade, where the price difference of homogenous goods will be less than or equal to transfer costs. Thus, the arbitrage conditions can be summarized as follows:

$$P_{1t} = P_{2t} + K_{12} \quad (1)$$

$$P_{1t} \leq P_{2t} + K_{12} \quad (2)$$

where P_{1t} and P_{2t} are the prices of a homogenous commodity in spatially separate markets and K_{12} denotes transfer costs. In empirical literature and when testing for the validity of the LOP, prices are usually expressed in logarithms, and the regression model of two price variables can be written as follows:

$$\ln P_{1t} = \ln \beta_0 + \beta_1 \ln P_{2t} + u_t \quad (3)$$

By applying the log on the price variables, the coefficients in equation (3) can be interpreted as elasticities of transmission. Given the strong version of arbitrage, i.e., prices move perfectly together over time, the necessary conditions for equation (3) are $\beta_0 = 0$, and $\beta_1 = 1$ (Vargova and Rajcaniova, 2018; Bacuks et al. 2019). However, apart from complete transference of information there are further requirements to consider with regard to effective arbitrage, including no market intervention or trade barriers and homogenous commodities. These conditions are rarely fulfilled completely and simultaneously in real world markets, and less so agricultural commodity markets (Pippenger and Phillips, 2008). In order to understand why, it is important to understand the characteristics of dairy products and dairy markets, as well as how different factors may affect or even impede price transmission, further discussed in section 3.4. Thus, since a strong version of the LOP rarely occurs, a weak version can be considered, implying that the necessary conditions for equation (3) become $\beta_0 \neq 0$ and $\beta_1 = 1$ (Bakucs et al. 2019).

3.4 Dairy characteristics and market inefficiencies

There are several reasons to why agricultural commodity markets might not in practice achieve the conditions suggested by economic theory, and thus, markets may not perform efficiently in terms of pricing. Some factors may be closely linked to characteristics of specific commodities while other relate more generally to differences in economies, government regulations, transfer costs, market imperfections, price shocks, inter alia (Pippenger and Phillips, 2008; Vargova and Rajcaniova, 2018; Baquedano and Liefert, 2014). This section aims to describe why perfect price transmission is not realistic by assessing some common limiting factors in price transmission as well as features specifically related to the dairy markets.

Baquedano and Liefert (2014) consider four main barriers in price transmission including: (1) price and border policies; (2) changes in exchange rates; (3) market structure, conditions and transaction costs; and (4) substitutability between domestic and foreign goods. While most of their findings are applicable in a Finnish or European context, some parts, such as weak infrastructure, are less so.

First, economic models generally assume no restrictions or market interventions. However, this is unrealistic in the EU due to high degree of regulation in agricultural markets, both by the Union and by individual states. Dairy markets have been subject to policy frameworks ever since the foundation of the CAP, and this comprehensive system of guidelines and standards imposes significant impact on market dynamics, structural development and milk price behavior.

Second, considering market structure and conditions, Baquedano and Liefert (2014) emphasize the significance of domestic market power in price transmission. For example, market power may impede border prices from transmitting to domestic prices as a result of the price setting potential of domestic producers. As briefly covered in section 2.1.2., Valio Group is an illustrative example from the Finnish dairy sector. With unquestionable market dominance both in milk collection and processing, Valio is considered to have a significant impact on how Finnish milk prices are formed. Contractual production practices applied by the company aims to balance supply and demand volumes and to avoid overproduction and dramatic price volatility. Such pricing behavior combined with the cooperative ownership nature of dairy companies and a high concentration ratio in the supply chain are considered key factors helping to explain the higher and more stable price levels in Finnish dairy markets when comparing to other countries (Rezitis, 2018; Latvala et al. 2022).

A third factor considered by Baquedano and Liefert (2014) is the substitutability between domestic and foreign products. This relates to the homogeneity of goods, a key assumption in price transmission theory and a requisite for the law of one price to hold. Hence, if goods are not homogenous, there is reason to assume that price transmission will be incomplete. It is an important

issue when considering milk, since some argue that milk quality may vary significantly between European countries (Vargova and Rajcaniova, 2018). According to Hamulczuk (2020), agricultural commodities may vary significantly in terms of quality and other parameters, depending on the origin, type of use and variety or breed. Contradicting with fundamental market theories such as the law of one price, this heterogeneity may affect the power of price transmission analyses. Furthermore, lacking information on trade costs, which is common in agricultural commodity studies also reduces the reliability of such analyses (Baquedano and Liefert 2014; Hamulczuk, 2020).

Thus, economic models often implies certain assumptions and conditions that are unlikely to hold in in the real world, especially in agricultural markets. Considering this, some important features of milk as a commodity should also be recognized. An essential attribute of milk relates to its perishability, which places limitations on the possibilities for trade over long distances and time. Milk is an unstable product that needs to be handled appropriately, at right temperatures (Bórawski et al., 2020). Also, the bulky nature of fresh milk makes transportation inefficient, a main reason to why raw milk is rarely traded ([OECD-FAO](#)). According to the FAO, only 8 % of the world milk production is traded in its liquid form.

Finally, Bakucs et al. (2019) emphasize how raw milk markets are organized in space. In their study on spatial price transmission they were able to reject the null of no cointegration only in 35 % of 380 country pairs, concluding that cointegration of milk prices in Europe is less prominent compared to other agricultural sectors. In contrast, Holst and von Cramon-Taubadel (2013) reached a rejection rate of 98 % when studying cointegration on European pork markets. Since the dairy sector is generally dependent on local collecting hubs and cooling facilities, pricing of milk may occur on a local level around collecting hubs rather than uniformly within a country's borders. This is likely to have an impact on price formation in separate regions, and consequently, national prices (at least within the EU) might not be fully representative for all geographic regions in a given country. Further, transportation of meat occurs at larger intervals and lower unit costs, while raw milk collection is almost a daily business (Bakucs et al. 2019).

4 Econometric time series analysis

4.1 Methodological approach

In agricultural markets, lack of appropriate data is often a key issue and may be a limiting factor in the choice of empirical method. Prices are often considered the only observable market parameter, while other forms of information, such as trade flows and transaction costs, may be scarcer. Thus, price transmission analysis has become an increasingly frequent way of studying markets, and the analysis of price cointegration and mutual adjustments in form of price transmission elasticities is a common approach to measure the degree of market efficiency (Jacks, 2005; Liu, 2011; Listorti and Eposti, 2012; Vasciaveo et al., 2013). In order to select an appropriate method in time series analysis, it is important to understand how variables behave, interact and integrate over time. When data characteristics are known, simple regression analysis can tell a lot about patterns and relationship between variables (Shrestha and Bhatta, 2018). This chapter aims to present some essential steps with regard to price transmission analysis and describe the methodological approach of this study.

There are several known methods to consider in price transmission analysis. Methods used in early literature, such as static regression analysis and simple correlation coefficients, have been criticized for disregarding dynamic effects and for not taking into account non-stationarity features in variables (Listorti and Eposti, 2012). From the 1990s onward, the concept of cointegration became increasingly prevalent, and more dynamic models, including the Engel-Granger two-step method (Engle and Granger, 1987) and the Johansen procedure (Johansen, 1991) were developed and widely adopted in cointegration analysis. Today, these methods are still the most commonly used among others in price transmission literature. While some evidence suggests that the Johansen procedure performs better than the EG method, the choice of method generally depends on the objective of the study (Faik, 1998). This paper aims to characterize price transmission between Finland and other, selected countries, not diagonal interactions between other countries or price steering dynamics or directions. Thus, the EG method is considered more than an adequate approach.

The Engle-Granger is a two-step method, where the first step is to generate residuals from a long-run relationship, estimated using standard ordinary least squares methods (OLS). Thus, the first step describes long-term dynamics, given that there exists an equilibrium. If cointegration is established, the second step uses the [lagged] residuals and the first difference of the lagged price variables to estimate an error correction model (ECM). That is, to estimate price adjustments from short-term deviations to the long-term equilibrium, or the error correction from disequilibrium (Engle and Granger, 1987). However, if a cointegration relationship cannot be established in the first step,

implying that there is no long-run equilibrium, one may proceed to studying short-run dynamics by estimating a dynamic OLS with lagged variables (Shrestha and Bhatta, 2018).

Figure 5 presents a scheme of a feasible methodological pathway in time series analysis, particularly considering the objective of this study. Thus, depending on the outcome of the cointegration analysis, the study may take two alternative approaches. If an equilibrium state is found, both long-run and short-run dynamics, i.e., actual price adjustments are studied. However, in case that cointegration is not established, focus is shifted to analyzing only short-term characteristics of Finnish milk prices.

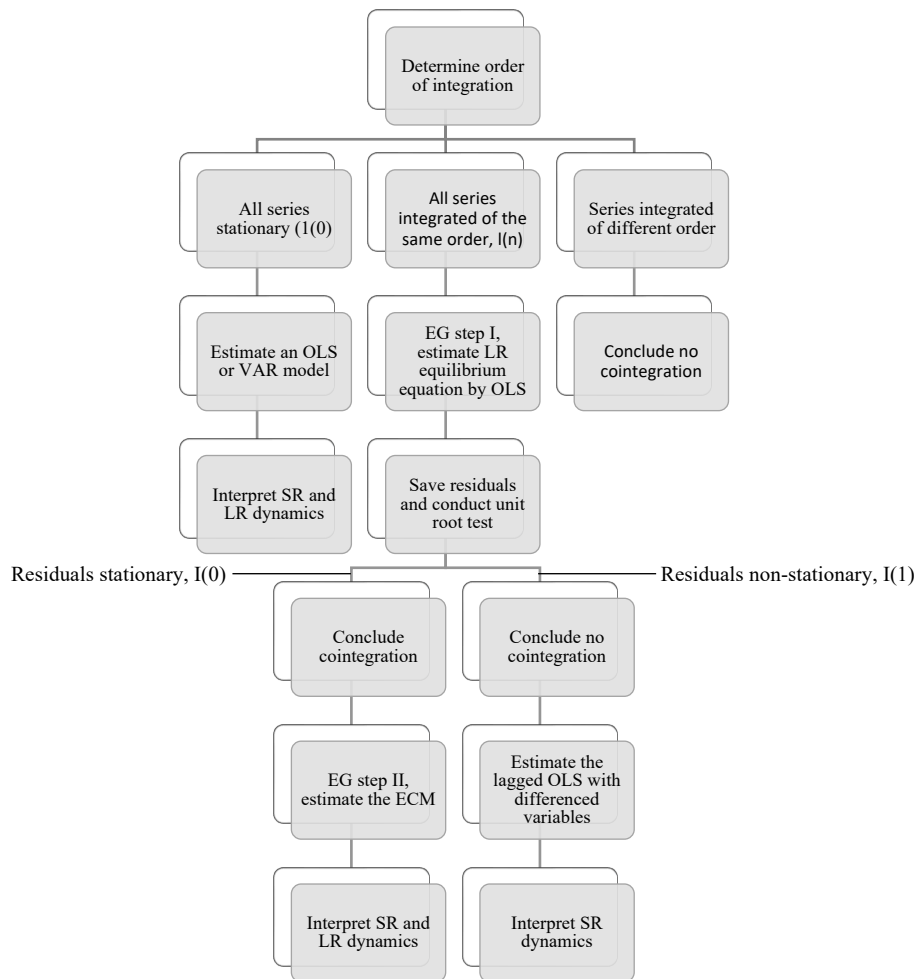


Fig.5. Methodological strategy for price transmission analysis. VAR: vector autoregressive; OLS: ordinary least squares; ECM: error correction model; SR: short-run; LR: long-run. Source: own elaboration based on Buteikis, 2020; Shrestha and Bhatta, 2018; Asteriou et al., 2016 and Vasciaveo et al., 2013

4.2 Order of integration and stationarity conditions

In order to select the appropriate method, the first step is to decide the order of integration of the variables. This is generally done by unit root tests, which determine the stationarity conditions of the variables. If a time series has a unit root, it is considered to be non-stationary. The selection of research method depends primarily on whether variables are integrated to the same or different order.

In other words, methods commonly used to analyze stationary time series should not be used to analyze non-stationary series, and vice versa. While a standard OLS regression or a vector autoregressive (VAR) model work well if all variables are stationary, these methods are likely to provide biased results if the variables are non-stationary. This is due to the so called spurious regression problem, implying an apparently significant relationship between unrelated variables (Asteriou et al., 2016; Shrestha and Bhatta, 2018).

To understand what a unit root essentially means, we consider a simple autoregressive model, AR(1):

$$Y_t = \phi Y_{t-1} + u_t \quad (4)$$

where u_t is white noise. Asteriou et al. (2016) suggest three possible scenarios:

- i) If $|\phi| < 1$, the series is said to be stationary, or I(0)
- ii) If $|\phi| > 1$, the series will explode since the variance grows exponentially
- iii) If $|\phi| = 1$, the series contains a unit root, implying that it is non-stationary, or I (d)

In a stationary process, statistical properties such as mean, variance and covariance do not vary with time. With other words, the process is time independent. Shocks will only be temporary since their effect will be eliminated as the series revert to the long-run mean. Thus, a stationary series has a stable and predictable behavior. On the other hand, a process that depends on time is said to be non-stationary, implying that its statistical properties change over time. The prediction of such process is more challenging. Non-stationary time series reflect a random process and may or may not have a drift component or a deterministic trend. Non-stationarity can result from several factors, including cyclical movements, seasonality, structural breaks or sudden shocks in the underlying process (Vasciaveo et al. 2013; Asteriou et al. 2016; Shrestha and Bhatta, 2018; Buteikis, 2020).

In economic data, non-stationarity is a common characteristic. Therefore, determining the stationarity conditions of the variables is a crucial step in order to select the proper method for price transmission analysis. However, non-stationary series can generally be made stationary through differencing. If a non-stationary variable becomes stationary after taking the first difference, it is considered integrated of order one, or I(1), implying that it contains one unit root. Similarly, if it becomes stationary after taking the second difference, it is considered integrated of order two, or I(2), containing two unit roots. If all variables are integrated to the same order, for example I(1), the possible cointegration relationship can be studied by the Engle-Granger procedure (Stock and Watson, 2020).

Considering the EG method, Asteriou et al. (2016) summarize three scenarios on how to proceed when having determined the order of integration:

- i) if all variables are stationary, $I(0)$, we do not continue with the EG approach since we can apply classical regression analysis such as a standard OLS or VAR model
- ii) if the variables have different order of integration, we conclude no cointegration, implying that there is no long-run linkage to further examine
- iii) if variables are integrated to the same order (e.g., $I(1)$), the variables may or may not be cointegrated, and we proceed with estimating the long-run regression by the first step of the EG approach or by applying an equivalent method for cointegration analysis

4.3 Traditional tests for stationarity

The traditional unit root tests used for statistically determining the stationarity of time series include the Augmented Dickey Fuller (ADF) test, the Phillips-Perron (PP) test as well as the Kwiatkowsky, Phillips, Schmidt and Shin (KPSS) test. In the ADF and PP tests, the null hypothesis (H_0) is that the series contains a unit root. In contrast, H_0 in the KPSS test is that the series is stationary (Shrestha and Bhatta, 2018). Unit root tests may depend on factors such as the model specification (e.g. trend or drift component or none of these) as well as on the sample size and the preferred level of significance, commonly 5 % (MacKinnon, J. G., 2010).

Considering an example, the ADF test on a series Y_t in a simple autoregressive model AR(1) can be written as:

$$\Delta Y_t = \mu + \phi Y_{t-1} + u_t \quad (5)$$

where,

$$\phi = \alpha - 1$$

α = coefficient of Y_{t-1}

ΔY_t = first difference of Y_t

Thus, H_0 is $\phi = 0$, whereas the alternative hypothesis is $\phi < 0$. If necessary, a trend or drift component $\beta_i D_{t-i}$ can be added to the model, depending on the characteristics of the data.

The PP test is fundamentally similar to the ADF, but although the ADF test sometimes is considered more reliable, the PP has been preferred for example for larger volumes of financial data (Shrestha and Bhatta, 2018).

Finally, the KPSS tests for stationarity using an alternative method with the opposite null hypothesis, i.e., stationarity. The method was originally developed in order cover some shortfalls of the ADF and PP tests, which are sometimes found to be biased towards accepting the H_0 . The KPSS model writes:

$$Y_t = X_t + \varepsilon_t \text{ and thus, } X_t = X_{t-1} + u_t \quad (6)$$

where the hypothesis is tested for u_t . In the KPSS test, the critical values are derived from the Lagrange Multiplier (Shrestha and Bhatta, 2018).

4.4 Engle-Granger step I – Cointegration analysis

Given that the variables are integrated of the same order, a standard OLS regression can be estimated to identify the long-run relationship between Y_t and X_t . The general form is:

$$Y_t = \beta_0 + \beta_1 X_t + u_t \quad (7)$$

where Y_t is the dependent variable, X_t the independent variable, β_0 a constant, β_1 represents the long-run effect and u the error term. Importantly, if the variables are non-stationary, the above regression may produce spurious results, implying that the estimates for β_0 and β_1 are biased. However, an exception is the special case where the variables are cointegrated. The intuition is that, although Y and X are non-stationary, or $I(n)$ with $n \geq 1$, there may be a common trend that links them together in the long-run. If a common long-run relationship exists, we should be able to find a linear combination of Y_t and X_t that is stationary, or $I(0)$, which has implications for the properties of the residuals (u_t) in the corresponding regression. Hence, given that the residuals are simply the difference between actual Y_t and estimated \hat{Y}_t , model (7) can be rewritten as:

$$\hat{u}_t = Y_t - \hat{Y}_t \quad (8)$$

$$= Y_t - \beta_0 - \beta_1 X_t \quad (9)$$

which, if Y_t and X_t are cointegrated, should be stationary. Thus, in order to establish cointegration, the residuals from the regression are saved and their stationarity condition examined by applying unit root tests, including ADF, PP and the KPSS tests. Since the tests are performed on residuals rather than on regular series, the critical values of the unit root tests are adjusted (MacKinnon, J. G., 2010).

If the errors are stationary, i.e., $\hat{u}_t = I(0)$, we conclude that there exists a cointegration relationship between Y_t and X_t , and the estimators of the regression are said to be super consistent (Asteriou et al., 2016; Shrestha and Bhatta, 2018; Stock and Watson, 2020). In this case we can proceed to the second step of the EG approach and estimate the ECM, covered in the next section.

4.5 Engle-Granger step II – Error correction model

The Granger Representation Theorem says that, if Y and X are cointegrated, then the relationship between them can always be expressed as an error correction model or an ECM (Engle and Granger, 1987). Thus, we can express the relationship between Y_t and X_t in a general form as:

$$\Delta Y_t = \alpha_0 + \beta_1 \Delta X_t - \pi \hat{u}_{t-1} + e_t \quad (10)$$

where, α is constant term, β_l is the short-run multiplier measuring the immediate effect that a change in X_t will have on a change in Y_t , while π is the coefficient of the lagged residuals, representing the feedback or adjustment effect. It tells the magnitude, or how much of the disequilibrium that is corrected during one period and it must be negative in order for the process to be stable. Finally, $\hat{u}_{t-1} = y_{t-1} - \hat{\beta}_1 - \hat{\beta}_2 x_{t-1}$ represents the error correction term, where $\hat{\beta}_2$ is the long-run response in the equation.

In model (10), everything is stationary since we have assumed that Y and X are both $I(1)$. Further, the residuals are stationary by the assumption of cointegration in step I. Thus, the model should perform well without risk for spurious estimations. In the context of price transmission analysis, such model provides information about the speed and adjustment of price transmission and is able to separate long-run and short-run information (Stock and Watson, 2020). The next section describes an alternative approach (see Figure 6), that is considered if a cointegration relationship is not established in the first step of the EG procedure.

4.6 Dynamic Ordinary Least Squares regression

If a cointegration relationship between the variables cannot be established, there is no point in estimating the error correction model. Instead, an alternative approach is considered and focus shifted to explaining short-run dynamics. This is done by estimating a dynamic OLS model, including the lagged and differenced values of dependent Y as well as the independent variable(s) X . The variables

are differenced in order to make them stationary and lagged in order to obtain the short-run information. Thus, a model with p lags of Y and q lags of X is:

$$\Delta Y_t = \alpha_0 + \alpha_1 \Delta Y_{t-p} + \beta_1 \Delta X_{t-q} + u_t \quad (11)$$

Model (11) differs from the ECM by not including the error correction term, i.e., the lagged residuals. Naturally, with several explanatory variables such as in this study, the model can be extended to include several independent variables. The presence of multiple predictors and their lags leads to double subscripting of the regression coefficients and regressors. Thus, the general form of a time series regression on differenced variables and with k predictors is:

$$\begin{aligned} \Delta Y_t = & \alpha_0 + \alpha_1 \Delta Y_{t-1} + \alpha_2 \Delta Y_{t-2} + \dots + \alpha_p \Delta Y_{t-p} \quad (12) \\ & + \beta_{11} \Delta X_{1t-1} + \beta_{12} \Delta X_{1t-2} + \dots + \beta_{1q_1} \Delta X_{1t-q_1} \\ & + \beta_{k1} \Delta X_{kt-1} + \beta_{k2} \Delta X_{kt-2} + \dots + \beta_{kq_k} \Delta X_{kt-q_k} + u_t, \end{aligned}$$

where q_1 is the number of lags of the first predictor, q_2 of the second predictor and q_k of the k^{th} predictor. Further, α_0 is a constant term, α_1 is the short-run effect measuring the immediate impact of Y on itself, while the β estimates measure the immediate impact a change in X_t will have on a change in Y_t . Since the variables are expressed in first difference, the regression is not spurious and the estimates of α and β are satisfactory (Stock and Watson, 2020).

The dynamic OSL model is estimated with appropriate specifications. For example, the inclusion of multiple lags of each variable is possible as long as it enhances the fit of the model, i.e., how well the model describes the variation in Finnish milk prices. Also, the inclusion of non-lagged price parameters can be tested. By estimating a range of models with different specifications, the ultimate model is chosen based on how well it explains the movements in Finnish milk prices. Hence, to choose a model that is robust and unbiased, the fitness of the model needs to be addressed by conducting diagnostics tests (Shrestha and Bhatta, 2018).

4.6.1 Goodness of fit and diagnostic tests

Generally suggested methods to infer the robustness of a regression model include examining its goodness of fit, studying the residuals, inter alia. Common goodness of fit tests are the R-squared (R^2) and adjusted R^2 , where higher values indicate a better fit, i.e., how well the regression line

explains the data. As long as R^2 increases when further explanatory variables or lags of these are added, the model is improving. Thus, the model with the highest R^2 can generally be preferred, although a high R^2 alone does not make the model robust. Goodness of fit can also be examined by using information criteria such as the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), both generally recommended methods for model selection. They estimate the relative amount of information lost by a given model by dealing with trade-offs between the goodness of fit and model simplicity, and the model with the best fit is the one that explains the greatest amount of variation using the fewest possible independent variables. When comparing models, the one with the lowest score is preferred (Shrestha and Bhatta, 2018).

Apart from goodness of fit statistics, another crucial part of the model diagnostics is the analysis of residuals. Since the least squares approach in OLS minimizes the errors, the residuals in a robust model should be just white noise, independently and identically distributed. Thus, an appropriate model should yield residuals that are not correlated, have a constant mean and variance and that are normally distributed (Hyndman and Athanasopoulos, 2018; Shrestha and Bhatta, 2018). Hence, the residuals are tested for autocorrelation and the results visualized by a correlogram, i.e., a plot of the autocorrelation function (ACF). If the spikes of the function lie within the given boarder lines, the residuals are considered white noise and there is no significant autocorrelation (Shrestha and Bhatta, 2018). Further, to account for the possibility of higher order serial correlation, the Breusch-Godfrey test is performed. If H_0 is not rejected, i.e., p-value of the test is > 0.05 , the residuals are not autocorrelated to any order less than or equal to the given order p .

The stability of the model is examined by computing empirical fluctuation processes according to a fluctuation test framework available in R package *strucchange*. The idea is to detect potential structural changes in the data. New, so called “recursive residuals” are generated and stability is tested on these with cumulative sums (CUSUMs) and moving sums (MOSUMs) processes. If the residual plots of the CUSUM and MOSUM processes lie within the 5 percent significance bands, the residuals are considered stable. On the other hand, if the processes exceed the boundaries, there is evidence for a structural change. If residuals are unstable, one might need to add more explanatory variables to improve the model, rather than adding or removing lags of variables already included in the regression (Zeileis et al. 2002; Shrestha and Bhatta, 2018).

The normality of the residuals is examined by applying the commonly suggested Shapiro-Wilk test for normality, which tests the H_0 of normal distribution against the alternative hypothesis that the residuals are not normally distributed. Normality of residuals is important for several reasons. For example, it affects the accuracy of the hypothesis tests and confidence intervals for the regression

coefficients. These are based on the standard errors of the estimates, which in turn depend on the normality of residuals (Hyndman and Athanasopoulos, 2018).

Finally, when choosing the ultimate model, attention is also given to the significance of the explanatory variables. For example, a model with higher R^2 may not necessarily be preferred if the significance of the explanatory parameters is lost. Hence, a lighter model may be preferred over a heavier, best-fit model, and vice versa, depending on the significance of the coefficients.

4.7 Data

The data used in the econometric analysis consists of monthly price data on raw milk, derived from the European Commission's milk market observatory. It reflects the average, monthly producer price of raw milk in respective countries over a time frame of ten years, from July 2013 until August of 2023, with a total of 122 observations.

The time frame of the study is selected to ignore data from the time before the entry into the EU as well as market shocks in the early 2000s. This is motivated partly because of the significant structural change seen in the dairy sector during the past decades, discussed in chapter two. The study aims to focus on the past decade, including one significant collapse of milk prices (2014-2016), a period of relatively stable prices (2017-2021) as well as a period of historical price peaks in recent years. Thus, the interval contains periods of significant volatility in both directions, as well as a less dramatic interval.

Apart from Finland, the neighboring countries Estonia, Sweden and Denmark are part of the study since, from a Finnish perspective, they are important trading partners. Further, Germany and France are included partly due to their dominant positions in the EU dairy markets, but also for being essential trading partners of Finland. Both factors may have implications for how Finnish milk prices are affected.

The price variables are specified in their log values since this is common procedure in price transmission analysis in order to obtain the price transmission elasticities. Figure 6 shows the price series of each country plotted over the selected time frame. In addition, the EU-27 average is plotted in black in order to give a visual idea of how prices of individual countries behave in relation to the average price of the Union. This variable is plotted for comparative purpose only and is not included in the econometric analysis.

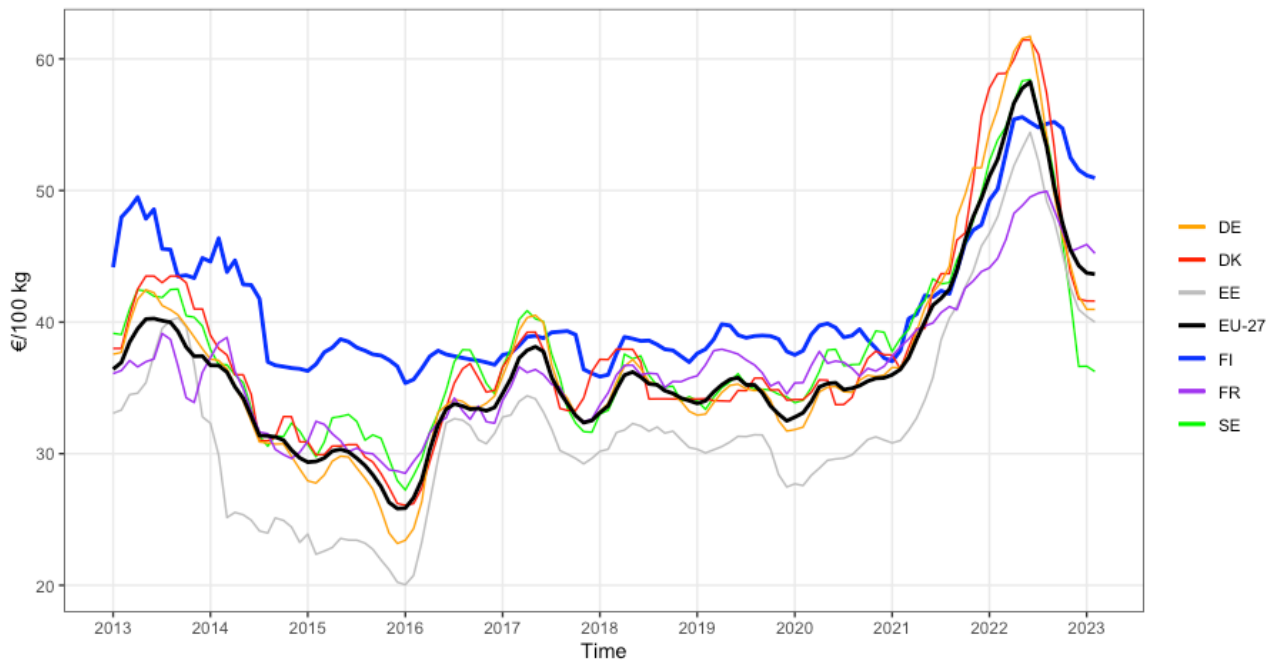


Fig. 6. Monthly price data, 2013-2023. Average raw milk prices (€/100kg) in Finland, Sweden, Denmark, Estonia, Germany and France. EU-27 average included for comparative purpose. Source: own calculations based on price data from European Commission.

Based on visual inspection of Figure 6 and the descriptive statistics in Table 2, a few presumptions can be made regarding the features of Finnish prices in relation to the other price series. First, as discussed earlier in section 2.1.2., Finnish milk prices generally seem to sit on a higher level than other European countries, as well as considerably higher than the EU-27 average (Rezitis, 2018; Arovuori et al. 2019). The average milk price for Finland over a ten year time frame is 41.24 €/100 kg, considerably higher than the second highest average reported for Denmark (37.91 €/100 kg). Second, during periods of high volatility Finnish prices appear more stable, i.e., the magnitude of price movements seems less dramatic. During the price peaks of 2022, Finnish milk prices reached a high of 55.58 €/100 kg, while prices exceeded 61.00 €/100 kg both in Denmark and Germany. The historical minimum is also considerably higher for Finland (35.37 €/100 kg) when compared to the other countries or the EU average (25.83 €/100 kg). Thirdly, although not fully consistent, there seem to be a delay of price movements in Finnish prices when comparing to other markets. For example, during the 2014-2016 crisis, Finnish milk prices began to fall only in mid 2014, while the European average price had been on a steady decline for a year already.

To summarize, by visual examination, it seems like Finnish prices perform rather independently, and the Finnish prices appear to have a less evident relation to the European average when compared to other countries of the study, with the exception of Estonia. These observations may justify the hypothesis that Finnish milk prices are not cointegrated with the prices of other EU countries.

However, although examining graphs and descriptive statistics is useful as a starting point and enables preliminary assumptions to be made, final conclusions cannot be drawn based on visual observations only. Thus, an important aim with the econometric analysis is to, by providing statistical evidence, enable conclusions with regard to these assumptions.

Table 2. Descriptive statistics of variables, actual prices and log prices (ln). Prices in €/100 kg, EU-27 included for comparative purpose. Source: own calculations.

Variable	Average	Min	Max	Std.Dev
FI	41.24	35.37	55.58	5.40
SE	37.74	27.24	58.43	6.46
DK	37.91	26.08	61.45	7.70
EE	32.38	20.04	54.42	7.74
DE	36.98	23.18	61.72	7.83
FR	36.52	28.51	49.95	4.94
EU-27	36.66	25.83	58.25	6.76
lnFI	3.71	3.56	4.01	0.12
lnSE	3.61	3.30	4.06	0.15
lnDK	3.61	3.26	4.11	0.18
lnEE	3.45	2.99	3.99	0.22
lnDE	3.59	3.14	4.12	0.19
lnFR	3.63	3.35	3.91	0.13
lnEU-27	3.58	3.25	4.06	0.17

5 Empirical results

5.1 Unit root tests

The results of the unit root tests conducted on each price series are presented in Table 3, including the ADF, PP and the KPSS tests for stationarity. Of the possible options in the ADF model specifications (“drift”, “trend” and “none”), the test was performed with a drift. Adding a trend component would imply that Finnish prices are systematically moving away from the other prices, which they do not seem to do. Looking at the price graph, there is no sign of an evident trend, reducing the chance of the data being trend stationary. Further, while choosing “none” as the model specification may be appropriate when regressing residuals, considering an expected mean around zero, this does not apply when using standard price variables. With regard to the PP test, the specification alternatives include a model with a constant or a model with a constant and trend. Since a trend still seems unlikely considering the data, more emphasis was given to the test including only a constant.

The ADF test with a drift component could not reject H_0 of unit root when the test was performed in levels. When taking the first difference, H_0 was strongly rejected, indicating that the series became stationary. The results of the PP test with a constant are similar and robust, and the first differences strongly rejects the null hypothesis of a unit root. Lastly, the KPSS test rejects H_0 of stationarity with variables in levels, although not on the differences, as expected. Hence, with similar results from three separate tests, the series were concluded integrated to the same order, i.e., of $I(1)$.

Table 3. Unit root test results, variables in levels and first difference.

Variable	ADF (“drift”)				PP (“const”)			KPSS (tau with 4 lags)			
	Stat. (level)	CV 5%	Stat. (1st dif.)	CV 5%	Stat. (level)	CV 5%	Stat. (1st dif.)	Stat. (level)	CV 5%	Stat. (1st dif.)	CV 5%
FI	-1.978	-2.88	-5.562	-1.95	-0.966	-2.885	-102.572	0.465	0.146	0.285	0.463
SE	-2.558	-2.88	-5.075	-1.95	-1.984	-2.885	-48.776	0.291	0.146	0.074	0.463
DK	-2.080	-2.88	-5.023	-1.95	-1.637	-2.885	-49.602	0.311	0.146	0.088	0.463
EE	-1.955	-2.88	-4.551	-1.95	-1.478	-2.885	-49.903	0.240	0.146	0.111	0.463
DE	-2.763	-2.88	-5.103	-1.95	-1.651	-2.885	-33.888	0.286	0.146	0.089	0.463
FR	-1.267	-2.88	-5.890	-1.95	-0.889	-2.885	-68.573	0.358	0.146	0.161	0.463

5.2 Cointegration analysis

Following the first step of the Engle-Granger two-step approach, the long-run relationship between Finnish milk prices and the other price series was examined by estimating a standard long-term OLS

regression. The estimated model (13) includes the log prices of Finnish milk as dependent variable and the log of Swedish, Danish, Estonian, German and French prices as explanatory variables. Since the price variables are in their log form, the β -constants can be interpreted as the elasticities of price transmission, implying perfect price transmission when $\beta=1$. The estimated coefficients of the regressions are expressed in model (14) with standard deviations in brackets.

$$\ln P_t^{FI} = \beta_0 + \beta_1 \ln P_t^{SE} + \beta_2 \ln P_t^{DK} + \beta_3 \ln P_t^{EE} + \beta_4 \ln P_t^{DE} + \beta_5 \ln P_t^{FR} + u_t \quad (13)$$

$$\begin{aligned} \ln P_t^{FI} = & 0.952 - 0.013 \ln P_t^{SE} + 0.529 \ln P_t^{DK} - 0.189 \ln P_t^{EE} & (14) \\ & (0.241) \quad (0.155) \quad (0.161) \quad (0.095) \\ & -0.053 \ln P_t^{DE} + 0.484 \ln P_t^{FR} + u_t \\ & (0.193) \quad (0.111) \end{aligned}$$

However, knowing that the variables in the regression are non-stationary in their levels, the estimates of this model could potentially be spurious, and thus, any further interpretation was not considered. Instead, by focusing on the residuals, the long-run linkage between the variables was examined. The residuals, \hat{u}_t , were obtained and tested for stationarity with appropriate unit root tests. Since the tests were performed on residuals rather than on regular price series, the use of adjusted critical values was crucial (MacKinnon, J. G., 2010). Also, since one may expect residuals to be stationary around zero if a cointegration relationship exists, the ADF test was performed with the model specification “none”, rather than with a trend or drift component as previously in 5.1.

Table 5 presents the result of the unit root tests on the residuals of Finnish milk prices. The ADF and Phillips-Perron test could not reject H_0 , indicating that the residuals are non-stationary. Further, the KPSS tests clearly rejected H_0 of stationarity. Thus, with three tests suggesting that the residuals contain a unit root, we conclude that the residuals are non-stationary and that Finnish milk prices are not cointegrated with prices of the other countries.

Table 5. Unit root tests on residuals from regression of Finnish prices on the other countries. Source: own calculations. Adjusted critical values from MacKinnon, J. G., 2010.

Test	H_0	Test statistic	Critical value 5%
ADF (“none”)	Non-stationary	-2.90	-3.78
PP (“const”)	Non-stationary	-2.50	-3.78
KPSS (tau with 4 lags)	Stationary	0.34	0.14

5.2.1 Comparative analysis

Beyond the main focus of this study, i.e., characteristics of Finnish milk prices, an extended analysis was performed for comparative purposes. The cointegration properties of all countries was examined separately, by exchanging Finland as the dependent variable. Similar long-run regressions were estimated for each country, and each set of residuals tested with corresponding unit root tests and adjusted critical values. Table 6 presents the result. The outcome was interesting, although not fully unexpected. In the ADF and PP tests, the unit root were robustly rejected for Danish and German residuals, although not for Swedish, Estonian or French residuals. This suggests that milk prices of Denmark and Germany respectively appear to have a relatively strong long-term interlinkage with other countries, i.e., evidence of cointegration. The same cannot be concluded for Swedish, Estonian and French prices based on the ADF and PP tests. However, the KPSS tests, performed both with short (4) and long (12) lags, did not reject H_0 for any country except Finland, providing some evidence for a cointegration relationship for Sweden, Estonia and France as well. Based on these observations, Finnish milk prices seem to be the most independently performing of all. Nevertheless, considering the cointegration relationships found for the other countries, a limitation of this analysis is worth reporting. Namely, a feasible scenario where Finland enters the cointegration vector of another country, implying a paradox when considering the results of the study more broadly, and thereby questioning the robustness of the approach. While acknowledged as a vent, the results of a multidimensional approach would be able to present such potential relationship. For example, methods such as the Johansen procedure, exhibiting several cointegration vectors simultaneously and more detailed interconnections could be applied for a more comprehensive investigation.

Table 6. Unit root tests on residuals from comparative regressions on each country separately. ADF test performed without drift or trend components, PP with constant and KPSS with type tau and short lags. Source: own calculations. Adjusted critical values from MacKinnon, J. G., 2010.

Variable	ADF ("none") H0 = non-stationary		PP ("const") H0 = non-stationary		KPSS (tau with 4 lags) H0 = stationary	
	Stat.	CV 5%	Stat.	CV 5%	Stat.	CV 5%
uFI	-2.90	-3.78	-2.50	-3.78	0.34	0.146
uDK	-5.53	-3.78	-4.511	-3.78	0.044	0.146
uSE	-3.57	-3.78	-3.276	-3.78	0.078	0.146
uEE	-3.32	-3.78	-3.353	-3.78	0.096	0.146
uDE	-5.84	-3.78	-4.195	-3.78	0.045	0.146
uFR	-3.64	-3.78	-3.014	-3.78	0.105	0.146

For visual purposes, Figure 7 shows the plotted residuals from the regression of Finnish prices (top left), as well as residuals from the comparative regressions. Recalling the conditions of stationarity, i.e., constant mean and variance, the graphic presentation appears coherent with the results of the unit root tests. It seems evident, that the Finnish residuals wander inconsistently from higher to lower values rather than moving around zero, indicating non-stationarity. On the other hand, residuals of Denmark and Germany respectively show a more consistent behavior, supporting the conclusion of stationarity.

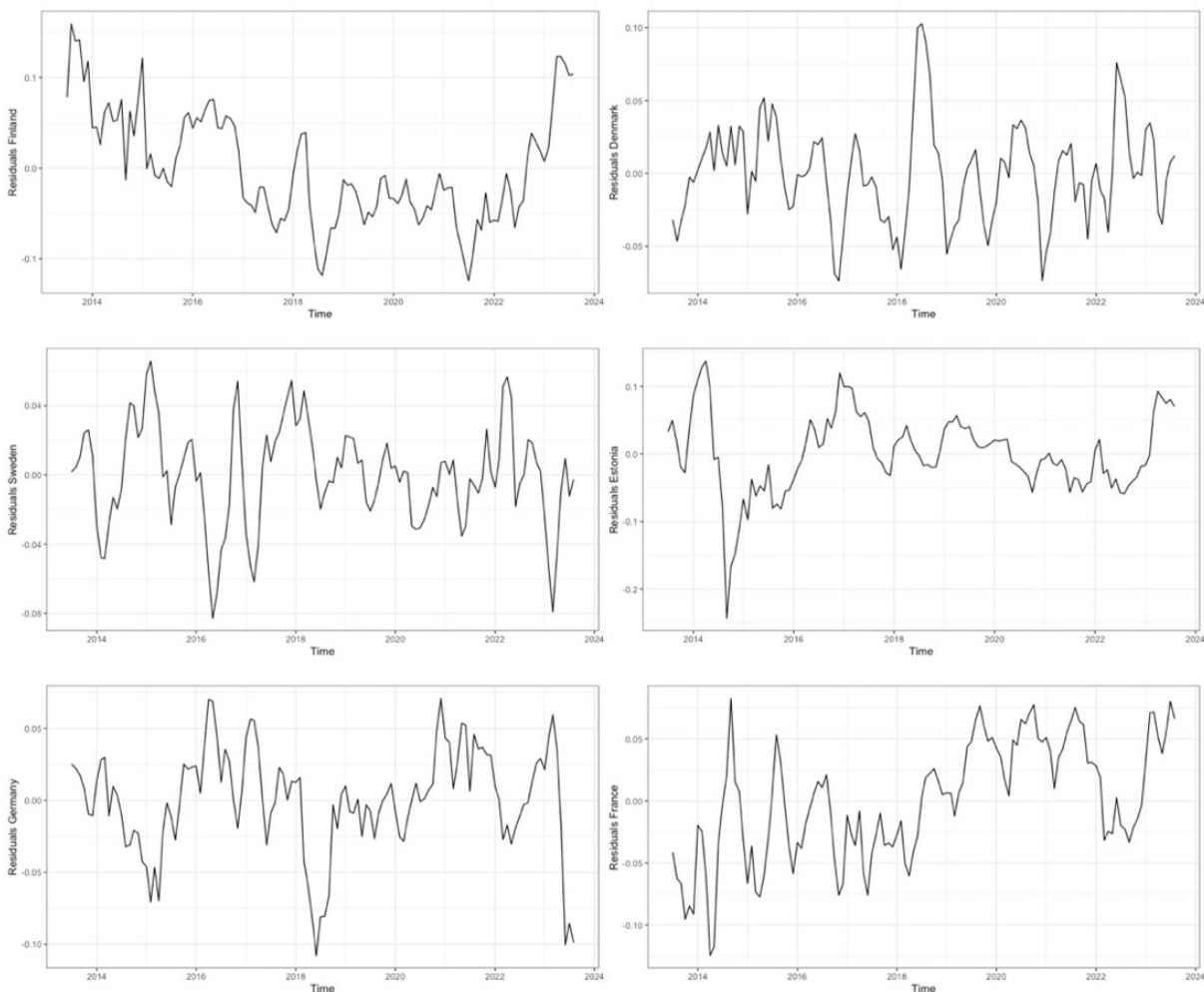


Fig. 7. Plotted residuals from OLS regressions on each country respectively, for comparative purposes. From upper left: FI, DK, SE, EE, DE and FR. Source: own calculations

5.3 Short-term model

Since a robust cointegration relationship could not be established between Finnish milk prices and the prices of the other countries, focus of the study was shifted to examining short-term characteristics of the Finnish prices. Thus, a dynamic OLS regression with lagged values of each price variable was estimated. In addition, since the variables were integrated of order one as previously demonstrated,

the variables were converted to their first difference. The final model (15) was selected after analyzing a range of models with different specifications, and after considering the factors discussed in section 4.6.1. regarding diagnostics and the fitness of the model.

$$\begin{aligned} \Delta \ln FI_t = & \alpha + \sum_{k \in \{0,2,5,6,8\}} \alpha_k \Delta \ln P_{t-k}^{FI} + \sum_{k \in \{0,2,5,6,8\}} \beta_{1k} \Delta \ln P_{t-k}^{SE} \quad (15) \\ & + \sum_{k \in \{0,2,5,6,8\}} \beta_{2k} \Delta \ln P_{t-k}^{DK} + \sum_{k \in \{0,2,5,6,8\}} \beta_{3k} \Delta \ln P_{t-k}^{EE} + \sum_{k \in \{0,2,5,6,8\}} \beta_{4k} \Delta \ln P_{t-k}^{DE} \\ & + \sum_{k \in \{0,2,5,6,8\}} \beta_{5k} \Delta \ln P_{t-k}^{FR} + u_t \end{aligned}$$

The final selection of lags was based on careful evaluation. Several different lag specifications were considered in the view of goodness of fit measures and the diagnostics discussed in section 4.6.1. Models including up to ten lagged price variables for each country as well as non-lagged variables were evaluated before selecting the final composition. The AIC and BIC results were also considered and weighted against other crucial factor such as variable significance and overall density of the model. However models marginally preferred by AIC and BIC were very heavy in terms of lag composition, although only few variables were significant. The R^2 was slightly lower in the chosen model, but the adjusted R^2 was still performing at its peak (without having started to revert such as in the case of even heavier models) and price variables were significant to a greater extent.

Thus, the final model included the second, fifth, sixth and eight lags of each explanatory variable, which all proved to contribute with significant explanatory power. Apart from the lagged values, a set of non-lagged variables was included, which too enhanced the explanatory power of model. The relatively high R^2 (0.597) and adjusted R^2 (0.456) values, implied that the regression explained almost 60 % of the short-term variation in Finnish milk prices. About one third (9 variables) of coefficients were statistically significant. While this may appear a minor share, adding more lags would only have a negative impact on the significance of the estimates and an adverse effect on the adjusted R^2 , implying that the addition of variables did not enhance the model any further.

5.3.1 Residual diagnostics

The residual diagnostics confirmed the robustness of the model, further justifying the selection of model specifications. First, the residuals did not suffer from significant autocorrelation (Figure 8), nor from serial correlation at a higher order. The null hypothesis of no autocorrelation was clearly not rejected at $p=29$ in the Breusch-Godfrey test. Second, H_0 was not rejected in the Shapiro-Wilk test

for normality (p-value = 0.12), verifying that the residuals were normally distributed, as desired. Figure 9 shows the distribution of the residuals in a standard histogram.

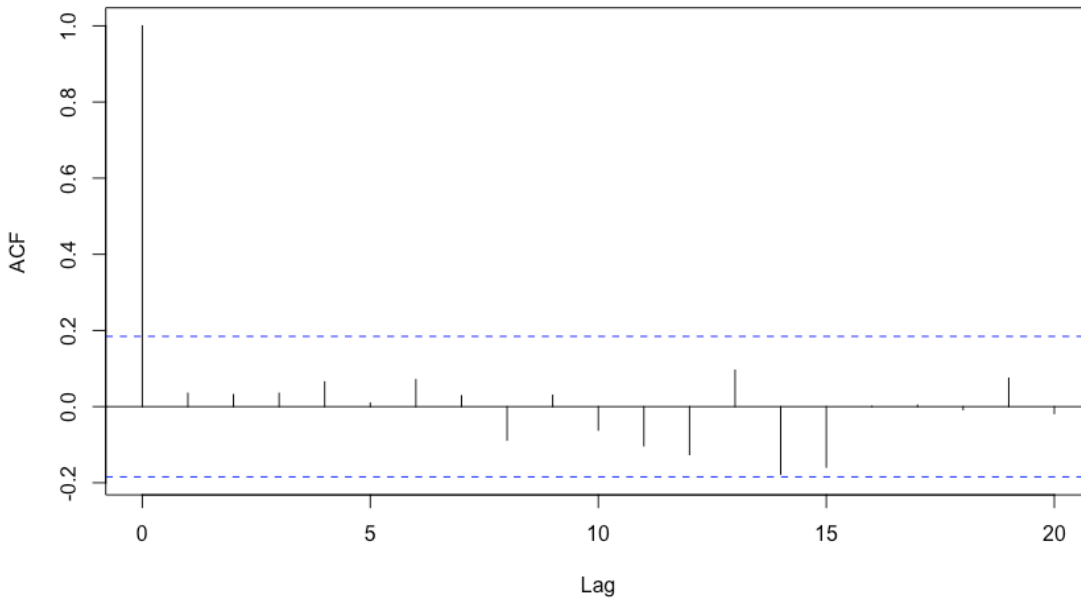


Fig. 8. Autocorrelation function (ACF) of residuals. Source: own calculations

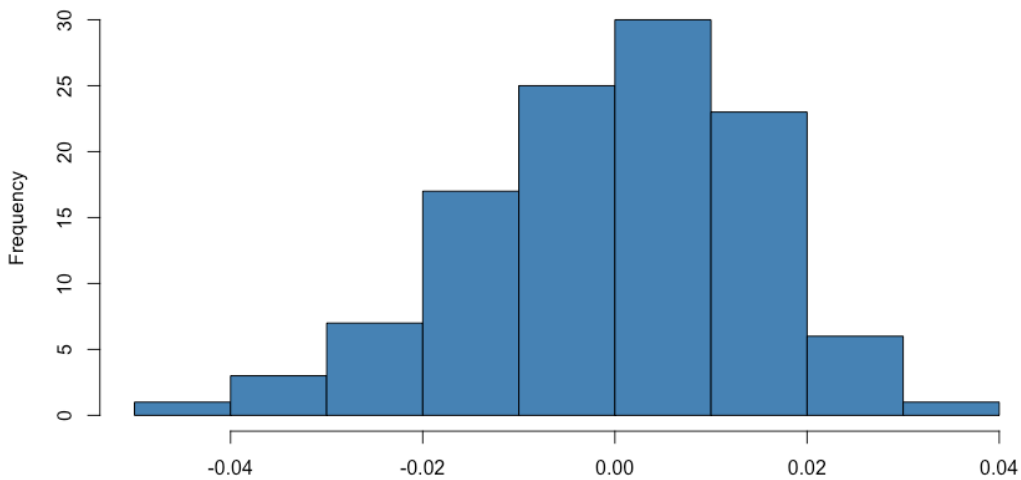


Fig. 9. Histogram of the distribution of residuals. Source: own calculations

Third, based on the CUSUM and MOSUM fluctuation processes (both with recursive and OLS residuals), no significant structural change was detected in the data. The plotted processes stayed within the 5 percent significant bands in all four tests, including two CUSUM and two MOSUM processes (see Figure 10).

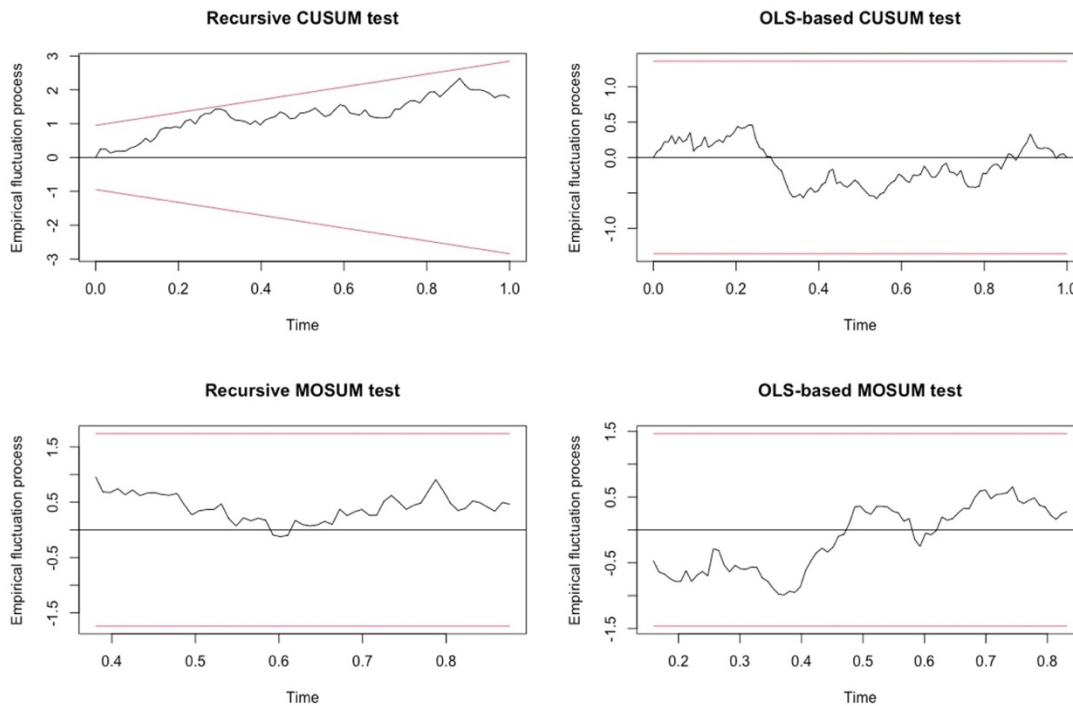


Fig. 10. Empirical fluctuation processes computed on recursive and OLS residuals. Red lines represent 5 percent significance bands. Source: own calculations

Further, by the significance tests applied on each process, H_0 of no structural change was not rejected in any test (Table 7), although the recursive CUSUM process was rather close to rejection. Based on these findings, the residuals were concluded stable, supporting the robustness of the model.

Table 7. Significance tests of the fluctuation processes. H_0 = no structural change. Source: own calculations

Process	P-value of significance test
Rec-CUSUM	0.068
OLS-CUSUM	0.891
Rec-MOSUM	0.456
OLS-MOSUM	0.336

5.3.2 Model estimates

Table 8 presents the results of the OLS regression, with the estimates . Of a total 29 explanatory variables, 9 were statistically significant. The coefficient of the 5th lag of Estonian (15d.EE) prices was positive and highly statistically significant beyond the commonly used 0.05 threshold value. Also, the 6th lag of Finnish (16d.FI) and 8th lag of French (18d.FR) prices were highly significant at a 0.1 %, and the non-lagged (current) prices of Denmark (d.DK), Estonia (d.EE) and France (d.FR) at

5 % level. Finally, the 2nd lags of Swedish (12d.SE), Estonian (12d.EE) and German (12d.DE) prices were significant at a 10 % level.

Table 8. Estimated OLS coefficients, significant estimates in the right-hand table. Numbering refers to lag length, d to the first difference. Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1. Source: own calculations

Variable	Estimate	Pr(> t)
(Intercept)	0,0008223	0,629887
d.SE	0,1170143	0,233962
d.DK	-0,195323	0,017586 *
d.EE	0,1711356	0,022359 *
d.DE	0,1392812	0,184098
d.FR	0,1854458	0,038217 *
12d.FI	0,0431303	0,647996
12d.SE	-0,167399	0,082359 .
12d.DK	-0,037469	0,704936
12d.EE	-0,149645	0,06001 .
12d.DE	0,1982984	0,081056 .
12d.FR	0,0461362	0,653838
15d.FI	0,0390869	0,653958
15d.SE	-0,100922	0,308244
15d.DK	-0,049713	0,567953
15d.EE	0,3170394	5,89E-05 ***
15d.DE	0,0081476	0,950386
15d.FR	-0,065148	0,481061
16d.FI	0,2850645	0,002738 **
16d.SE	-0,006249	0,946281
16d.DK	0,0834044	0,376321
16d.EE	0,0952538	0,231665
16d.DE	-0,05378	0,663944
16d.FR	-0,10856	0,259413
18d.FI	0,0471352	0,576398
18d.SE	-0,080012	0,450899
18d.DK	0,0950113	0,26018
18d.EE	0,0025051	0,972705
18d.DE	-0,089538	0,469596
18d.FR	-0,269701	0,004735 **

Variable	Estimate	Pr(> t)
d.DK	-0,19532	0,017586 *
d.EE	0,171136	0,022359 *
d.FR	0,185446	0,038217 *
12d.SE	-0,1674	0,082359 .
12d.EE	-0,14965	0,06001 .
12d.DE	0,198298	0,081056 .
15d.EE	0,317039	5,89E-05 ***
16d.FI	0,285064	0,002738 **
18d.FR	-0,2697	0,004735 **

According to the model, Finnish milk prices appear to be influenced French prices both in present time as well as, even more so, over an extended time frame (with a lag of eight months). However, while the sign of the estimate was positive for the non-lagged variable (0.185), it was negative in the eight lag (-0.269). A second implication of the model refers to the seemingly strong relation between Finnish and Estonian milk prices. Three of the Estonian coefficients were statistically significant, including the non-lagged (0.171) and fifth lag (0.317), positively and highly significant, as well as the second lag (-0.149) with a negative sign, but only significant at a 10 % level.

A third inference of the regression outcome is the fact that Sweden and Germany seem to have a marginal impact on the short-term performance of Finnish milk prices. Only the second lag of Swedish (-0.167) and German (0.198) prices were statistically significant, yet only at a 10 % level.

6 Discussion

The first part of this study, comprising cointegration analysis, confirms an independent performance of Finnish milk prices when compared to those of other European countries. This observation contrasts with some prior studies, including Katrakilidis (2008), Vargova and Rajcaniova (2018), and Jurkenaite and Mikelionyte (2021), which nevertheless are limited to specific country groups, excluding Finland, and mostly focus on larger milk producers in Europe. On the other hand, a comprehensive EU-wide study by Bacuks et al. (2019) supports the findings of this paper, revealing weak price transmission in dairy markets compared to other agricultural sectors.

Although Finland is highly reliant on the EU markets both in terms of dairy imports and exports, considering the absence of cointegration, price equalization with its trading partners seems not to hold. In view of the initial hypothesis of this paper regarding the deviating performance of Finnish milk prices when compared to other countries, this result is not very unexpected. The outcome is rationalized by several factors that have been thoroughly discussed in this paper, including some general characteristics of dairy markets and related inefficiencies (section 3.4. and 2.1.). For example, high concentration of the dairy processing industry and retail, the cooperative ownership of dairy companies in Finland, as well as features related to milk as a relatively heterogenous commodity, arguably also when considering raw milk. Also, the structure and patterns of dairy trade, including high level of intra-industry trade and advanced product differentiation are factors to consider crucial. While raw milk is rarely traded, processed products subject to trade are generally heterogenous to a varying degree. In addition, the strong preference for domestic products among Finnish consumers may contribute significantly to the competitive status of the domestic dairy sector, further challenging the applicability of concepts like spatial arbitrage and the LOP in practice. However, while maintaining higher raw milk prices may be crucial for the competitiveness of the Finnish dairy sector, comprehending the actual reasons to the absence of cointegration is crucial, not least when considering the difference in policy implications. Thus, whether it is due to erroneous assumptions of the economic model (e.g. referring to the homogeneity of milk as a commodity), or due to the presence of evident market inefficiencies are key issues that require further examination.

The second part of the price analysis indicated that, despite lack of a common long-term equilibrium, Finnish milk prices seem affected by prices of other countries in the short-run (SR). The dynamic OLS regression was able to explain approximately 60 % of SR fluctuations in Finnish milk prices. Unexpectedly, Swedish and German milk prices exhibit seemingly negligible influence, challenging the expectations given the significant trade relations between these countries and Finland. However, as discussed in this paper, physical trade is not a condition for price transmission to occur, a

hypothesis clearly supported by these results. Instead, differences in domestic regulations or market structure in these countries may be of higher importance when considering the weak SR associations. Cooperative ownership of dairy companies or contractual arrangements typical for the Finnish dairy sector may also play key roles, considering the importance of balance between supply and demand in stabilizing price fluctuations. Further, the fact that milk is a perishable good makes distribution of sudden surpluses hard. Although some surpluses can be converted into less perishable goods for later consumption or export, fresh milk products still constitute an important part of intra-EU trade.

Notably, the most evident SR associations identified were Finnish-Estonian and Finnish-French milk prices. While lacking a clear explanation, especially regarding interpretation of specific lags, some potential factors can be considered. From a trade perspective, France is the second largest export market for Finnish dairy products inside the EU, although this (as earlier discussed) is unlikely to justify the connections between Finnish and French prices. Similarities in domestic policies or how Finnish and French markets are structured may be of greater importance. Further, the rather strong SR interconnections between Estonian and Finnish milk prices could appear logical considering the geographical proximity of the countries. Importantly, Estonian milk prices on average are substantially lower than Finnish ones, and the country has a long history of milk surpluses. Such cost advantage may influence Finnish milk prices in the short-run, especially considering that a major part of Estonian exports composes raw milk or other fresh dairy products. Hence, while challenges persist in fully explaining the SR dynamics of Finnish milk prices, it is essential to recognize the shortcomings of the study, further discussed in the next section.

6.1 Limitations of the study

It is acknowledged, that this analysis exhibit some deficiencies and methodological limitations. Firstly, the selection of countries and chosen time frame for the study could have been extended or otherwise modified, potentially enhancing the adequateness of the analysis. Secondly, the exclusion of exogenous variables, such as prices of agricultural inputs (e.g., energy, fertilizers, animal feed), from the dynamic OLS model represents a potential limitation. Including such variables may have offered a more nuanced description of the short-run price behavior. While the primary focus of this study was to elucidate Finnish milk prices through the influence of other countries' milk prices, the exclusion of other, external factors in the study should certainly be recognized, since it may be considered a weakness in price transmission approaches more broadly.

Thirdly, the choice of the cointegration analysis method involved some trade-offs, referring to the selection of the Engle-Granger (EG) approach over the Johansen procedure. While the EG approach

is conceptually straightforward, it entails methodological shortcomings, as briefly outlined in section 4.1. Asteriou et al. (2016) lists three important issues related to: variable order, multiple cointegrating vectors, and the two-step nature of the method. In the long-run regression, the dependent variable is set to the left side, while other variables are used as regressors. However, the test does not say which variable to use as regressor and why. According to Asteriou et al. (2016), asymptotic theory can prove that, as a sample goes to infinity, cointegration tests on the residuals are going to be equivalent. In theory this implies that the unit root test is indifferent to which variable is used as dependent. In practice however, economic data samples are likely to be less than infinite in size, making it possible to observe whether a regression exhibits cointegration or not. The second issue refers to the number of cointegrating vectors. In a model with more than two variables there may be more than one cointegrating vector. Since the EG method uses the residuals from a single relationship, it cannot treat this possibility. The comparative analysis in section 5.2.1. was conducted partly in order to address this issue by detecting other cointegrating relationships and placing the Finnish results in a broader perspective. The third problem concerns the two-step nature of the EG method, implying that any error in the first step will be carried into the second. However, despite the prevalence of the Johansen procedure in cointegration analysis due to its resolution of the outlined issues, the EG approach was deemed suitable for this study, given its alignment with the study's framework and objectives.

Another commonly acknowledged deficiency in price transmission analysis and regarding arbitrage theory in general pertains to the availability and the characteristics of data. It is important not least in the agricultural sector, where critical information such as transfer costs is rarely available. Furthermore, the frequency of price data in agriculture markets tends to be lower compared to other commodities or financial instruments. Recognizing the impact of these data-related constraints on econometric analysis is vital. However, while understanding these limitations is crucial, it is important to note that, without general improvements in data availability in agricultural markets, such challenges are inherent in the field, posing minor impediments to cross-study comparability.

Ultimately, it is important to recognize the risks regarding the dynamic factors and lag structure of the SR model. It is plausible, that different lag structures may capture different aspects of SR dynamics, and consequently, the impact of individual lags may conceivably be arbitrary rather than systematic. Addressing this deficiency requires trials with alternative lag specifications and comparable analysis. Although this was certainly part of the procedure when selecting and assembling the SR model of this study, considering potential impacts on the regression outcome, the importance of a careful selection of variables, lags, as well as time frame of the study cannot be stressed enough.

7 Conclusions

This paper has analyzed the characteristics of Finnish milk prices in relation to major EU trading partners. One key objective was to determine whether a cointegration relationship exists, and if so, to describe the horizontal price transmission features between Finnish and other dairy markets, including how fast and to what extent prices are transmitted. Significant cointegration could not be established, implying that Finnish milk prices evolve quite independently over the long-run rather than sharing a common equilibrium with the prices of Finland's major trading partners. This outcome was not totally unexpected and in line with the initial hypothesis presented with regard to the autonomy of Finnish milk prices in an EU context (section 4.7). Further, these findings are supported for example by Bacuks et al. (2019), showing that cointegration in European dairy markets is less prominent when compared to other sectors. The results are likely to be explained partly by the characteristics of the dairy sector, both at domestic and EU-levels. Major features include the cooperative ownership of dairy companies in Finland, allowing for more independent price setting practices. Further, consumer preferences may play a key role when considering the competitive status of the sector, referring to the strong demand of domestic dairy products in Finland. Other crucial factors relate to the characteristics of milk as a commodity and the structure of dairy trade. Liquid milk is rarely traded, and yet, price transmission analyses are generally conducted on raw milk prices. The sector is characterized by a heterogenous product supply, and countries do not generally import the same goods as they export (section 2.1.3.), which in part may be explained by advanced product differentiation. Differentiation is clearly an important factor that adds value throughout the supply chain. In the case of Finland, affluent innovation and product differentiation, also considering less perishable goods such as milk powder, seem to allow for a competitive export market despite higher production and transfer costs when compared to other European countries.

The second part of the study confirmed that Finnish milk prices indeed are affected by prices of other countries, including France and Estonia, in the short-run, although the justification of specific price associations remained at the level of presenting hypotheses rather than robust conclusions. Inevitably, SR dynamics are more challenging to model, one reason considered being the risk that individual impacts captured by a model may prove to be random rather than systematic. Future data on milk prices will give valuable insights with regard to the implications of recent market shocks and whether impacts have been temporary or persistent. As agricultural commodity markets may well continue to perform with increased level of volatility, there will certainly be incentives to pursue further research in the field of price transmission.

8 References

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Appendices