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Price Linkages in major EU Olive oil Markets

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ABSTRACT

This thesis analyses price relations in virgin and extra virgin olive oil markets focusing on Spain, Italy, and Greece. Research investigating price dependence in these markets is limited. Therefore, this study examines the degree of market integration and efficiency, as well as price leadership through short and long-run relations, considering structural breaks and possible asymmetries in the price transmission process. This is pursued using a mixed method approach utilising both qualitative and quantitative tools.

The literature review chapter employs a systematic map to collate existing evidence around price dependence in EU edible oil markets spanning the period 1993-2020, and to contextualise the research gap. Results yield mixed evidence regarding price patterns in EU edible oil markets, with most sources confirming the presence of asymmetries.

Furthermore, the empirical chapter is divided into two sub-sections analysing two olive oil qualities: virgin and extra virgin olive oil. Wholesale monthly price data for Spain, Italy, and Greece are employed covering the period 2000-2022. Regarding virgin olive oil, results from Diks-Panchenko causality test indicate that Spain leads price formation. Although market integration is supported through the Momentum Threshold Autoregressive model, asymmetries are present between Italy-Spain and Greece-Spain. However, a symmetric pattern is revealed for Greece-Italy and the Law of One Price is confirmed. In terms of extra virgin olive oil, results from the Hacker-Hatemi-J and Diks-Panchenko causality tests identify Italy as the central market. Market integration is confirmed through the Non-linear Autoregressive Distributed Lag model with a weaker cointegrating relationship for Italy-Spain, and mixed results regarding the price transmission pattern for all pairs. Symmetry is only confirmed in the case of Italy-Spain; however, the Law of One Price is rejected, suggesting inefficiencies in the markets. Thus, the need for further research to recommend policy interventions is highlighted.

This thesis is dedicated

To my beloved parents, Georgios and Maria, who have always been a source of inspiration

and encouragement, and taught me to face life with zeal, enthusiasm, and courage.

“I hope I made you proud!”

To my husband, Dimosthenis, for standing by me

through my highs and lows.

To my dear brother and sister, Rogiros and Lefki,

for believing in me and keeping me positive.

To my grandmother, Pepa, as

a sign of respect and

appreciation.

In loving memory of my grandparents

Yiannakis, Rogiros and Lefki.

“Though you never got to

see this, you’re

in every

page”

Pamela Theofanous

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List of Abbreviations

Abbreviation	Definition
ADF	Augmented Dickey-Fuller
AECM	Asymmetric Error Correction Model
AECM	Asymmetric Error Correction Model
AI	Avian Influenza
AIK	Akaike Information Criterion
AJG	Academic Journal Guide
APT	Asymmetric Price Transmission
APVT	Asymmetric Price Volatility Transmission
ARCH	Autoregressive Conditional Heteroskedasticity
ARDL	Autoregressive Distributed Lag
ARMA	Autoregressive Moving Average
BEKK	Baba, Engle, Kraft and Kroner
BR	Brazil
BSE	Bovine Spongiform Encephalopathy
CAP	Common Agricultural Policy
CIF	Cost, Insurance and Freight
CN	China
CP	Consumer Prices
CPO	Crude Palm Oil
CPT	Carriage Paid To
DE	Germany
DOLS	Dynamic Ordinary Least Squares
EC	European Commission
ECM	Error Correction Model
EL	Greece

ES	**Spain**
EU	**European Union**
EVOO	**Extra Virgin Olive Oil**
FAO	**Food and Agriculture Organization of the United Nations**
FC	**Future Contracts**
FEV	**Forecast Error Variance**
FOB	**Free on board**
FR	**France**
GARCH	**Generalized Autoregressive Conditional Heteroskedasticity**
GJR	**Glosten, Jagannathan, and Runkle model**
GLS-ADF	**Generalized Least Square Augmented Dickey-Fuller**
GR	**Greece**
IRF	**Impulse Response Function**
IT	**Italy**
KPSS	**Kwiatkowski–Phillips–Schmidt–Shin**
LBA	**Licensed Buying Agents**
LM	**Lagrange Multiplier**
LOOP	**Law of One Price**
LOP	**Law of One Price**
MI	**Market Integration**
ML	**Maximum Likelihood**
MS VECM	**Markov-switching Vector Error Correction Model**
MTAR	**Momentum Threshold Autoregressive**
NARDL	**Non-linear Asymmetric Autoregressive Distributed Lag**
OC	**Oceania**
OLS	**Ordinary Least Squares**
PMI	**Partial Market Integration**

PP	**Phillips-Perron**
PRISMA	**Preferred Reporting Items for Systematic Reviews and Meta-Analyses**
PT	**Portugal**
PT	**Price Transmission**
PVT	**Price Volatility Transmission**
RP	**Retail Prices**
RSVECM	**Regime-Switching Vector Error Correction Model**
SC	**Serial Correlation**
SIC	**Schwarz Information Criterion**
SJR	**SCImago Journal Rank**
TAK	**Title-Abstract-Keyword**
TAR	**Threshold Autoregressive**
TR	**Turkey**
UA	**Ukraine**
UK	**United Kingdom**
US	**United States**
USA	**United States of America**
VAR	**Vector Autoregressive**
VECM	**Vector Error Correction Model**
VOO	**Virgin Olive Oil**
WP	**Wholesale Prices**

Chapter 1 Introduction

Since 1990, the European Commission has implemented significant initiatives towards the integration of national markets. The establishment of the single market in 1993 further stimulated the unrestricted movement of goods, individuals, services, and capital, as noted by Borchert and Reineke (2007). The establishment of the Eurozone has upgraded the level of transparency due to the single currency, reducing volatility and risk spillover related to trade (Borchert and Reineke, 2007). At the same time, significant actions have been taken to foster competition and to minimise deformations associated with policy intervention from governments. However, there are clear indications that the dispersion of prices remains over time, while prices for almost identical products are not entirely comparable in neighbouring countries (Emmanouilides and Fousekis, 2012).

Considering that, agricultural and food products' price relations in separated markets and along the supply chain have attracted the interest of both academics and policymakers (Conforti, 2004). The interest in analysing the intensity and pattern of price transmission arises from the belief that this provides valuable insights into the integration of markets, whether in the context of globalization or market segmentation, as noted by Fackler and Goodwin (2001). Highly integrated markets are characterised by price dependence; thus, a shock that originates in one market evokes a response in the other (Meyer and von Cramon-Taubadel, 2004). Price transmission is considered to be a necessary condition for achieving economic efficiency and maximizing the benefits of spatial arbitrage (Serra *et al.*, 2006a).

According to the literature, there are two primary types of price transmission: vertical and horizontal. Vertical price transmission involves the movement of prices along different levels of a supply chain, specifically from retailers to farmers, as noted by Santeramo *et al.* (2016) and Ricci *et al.* (2019). Conversely, horizontal price transmission relates to the process of price pass-through between different commodities, as emphasized by Kharin (2019) (e.g. between pork and poultry supply chains) or between different markets/geographical locations for the same commodity, namely spatial PT (von Cramon-Taubadel and Goodwin, 2021) (e.g. between UK pork market and EU pork market). All types of price transmission have been extensively analysed through different commodity markets, including agricultural commodity markets and non-agricultural commodity markets.

The interest regarding price transmission under market integration is due to several factors. First, price changes in different parts of the supply chain and between different markets have important implications for consumers and producers' welfare. Therefore, the investigation of price linkages is essential both for policymakers in agriculture and economists (Sexton and Lavoie, 2001). Additionally, based on classical economic theory, prices include information regarding the scarcity and/or availability of goods. Thus, exploring price changes is directly related to whether available resources are rationally distributed and used optimally in agricultural production (Bakucs *et al.,* 2015). Moreover, price transmission analysis of food products informs about market competitiveness, so it attracts the interest of regulatory authorities (McCorriston, 2002).

Price relations in literature are analysed through three dimensions: the market integration, the spatial arbitrage - efficiency of the markets through the Law of One Price and the pattern of price transmission. Investigating the pattern of price transmission can provide invaluable information about the efficiency or inefficiency of a market. In particular, an asymmetric pattern can indicate that the market under examination is inefficient. There are several possible causes of asymmetric price transmission that relate to different aspects of market characteristics, product characteristics and external factors. For example, market power (Abdulai, 2000; Bakucs *et al.,* 2013), market structure (Peltzman, 2000; Acosta and Valdés, 2014; Panagiotou, 2018), incomplete information (Aramyan and Kuiper, 2009) and trade-related causes (Goodwin and Piggott, 2001; Goez *et al*., 2008; Goetz *et al.*, 2008) can affect the pattern of the price transmission and contribute to, or lead to asymmetries. Product-related factors can also affect the price transmission process, such as product homogeneity and differentiation (Goshray, 2009; Emmanouilides and Fousekis, 2012), consumer preferences and search costs (Loy *et al.*, 2019; Emmanouilides and Fousekis, 2014a), and product perishability and storage (Santeramo and Cramon-Taubadel, 2016; Hillen, 2021). Other factors that are indirectly product-related are stock practices and inventory management (Rapsomanikis *et al.*, 2003; Emmanouilides and Fousekis, 2012), transport and transaction costs (Conforti, 2004) and production-related causes (Aramyan and Kuiper, 2009; Bor *et al.*, 2013). Furthermore, external influences include food scares (Tremma and Semos, 2017), government intervention (Gotz *et al.*, 2012; Emmanouilides *et al.*, 2014), and exchange rates (Conforti, 2004).

Exploring the degree of price integration among the EU markets and along the EU supply chains has attracted the interest of many researchers the last 30 years (Zanias, 1993; von Cramon-Taubadel and Meyer, 2000; Baffes and Ajwad, 2001; Gauthier and Zapata, 2001; Thompson *et al.,* 2002; Rapsomanikis *et al.,* 2003; von Cramon-Taubadel *et al.*, 2006; Vavra and Goodwin, 2005; Serra *et al.,* 2006a; 2006b; Fousekis, 2007; Ghoshray, 2009; Emmanouilides and Fousekis, 2012; Karikallio, 2015; Fousekis, 2015; Grigoriadis *et al.,* 2016; Loy *et al.*, 2019). Nevertheless, a significant proportion of the existing literature on price transmission concentrates on agricultural commodities that are predominantly consumed and produced in Northern European countries, particularly meat (Vavra and

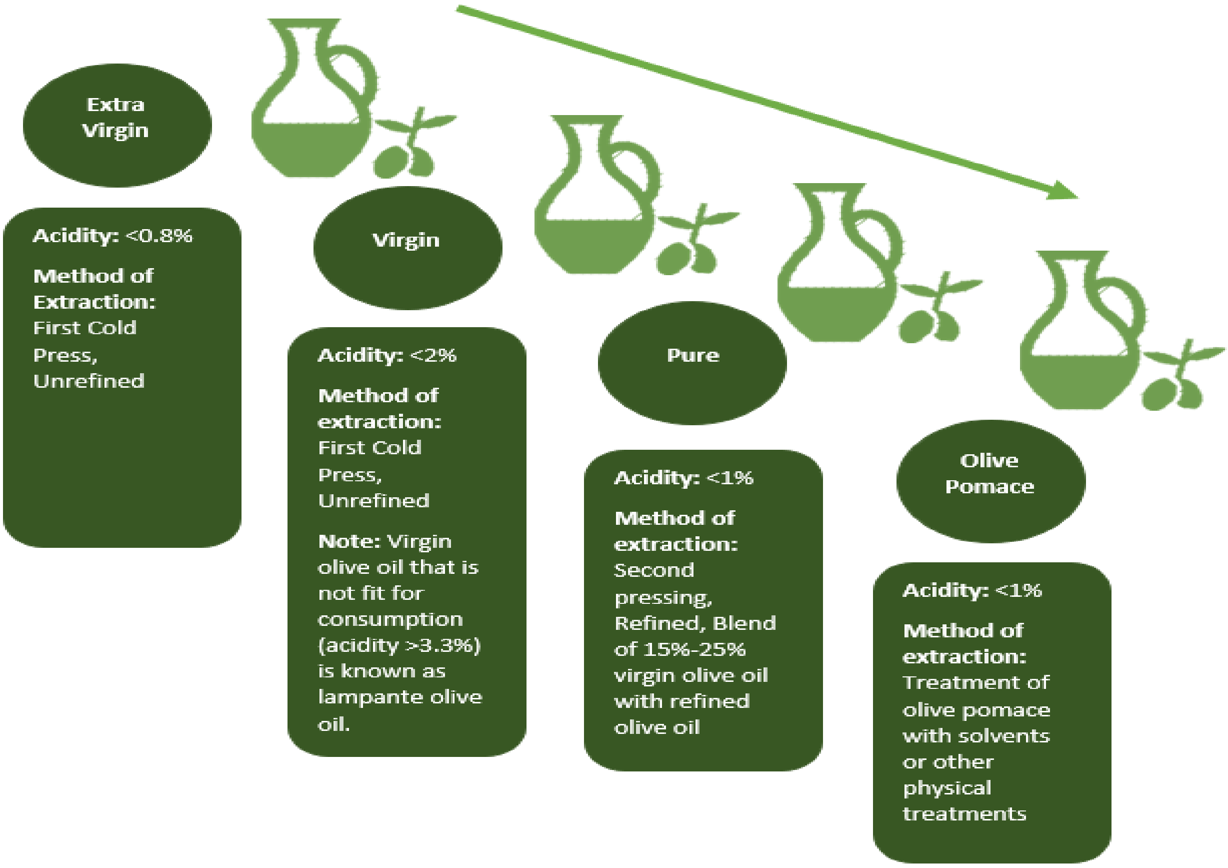
Goodwin, 2005; Fousekis, 2015), dairy (Fousekis and Trachanas, 2016; Rudinskaya and Boskova, 2021), cereal (Ghoshray, 2008; Gedara *et al.*, 2015), fish (Gonzales *et al.*, 2002; Asche *et al.*, 2007; Gizaw *et al.*, 2021), seeds (Worako *et al.*, 2008) and fruits and vegetables (Acharya *et al.*, 2011; Ahmed, 2018), while a small number of studies examines the olive oil markets. However, its importance is paramount mainly due to its attributes, contribution to local economies and sustainability.

1.1 The Global Olive Oil Market

According to Brown (2020), olive oil is the most notable agricultural product of the Mediterranean region and has gained global recognition owing to its perceived health benefits. Olive oil plays a crucial role in the Mediterranean Diet, which is renowned for being one of the healthiest diets worldwide, largely due to the inclusion of olive oil. In recent years, a key consideration in policy reforms and consumer purchasing behaviour is sustainability. In this vein, the Mediterranean diet is considered a sustainable diet because it has lower water, soil and energy requirements in terms of the associated production (Pairotti *et al.*, 2015). In comparison, more conventional consumption habits like Western or meat-based diets have a higher environmental footprint (Carzedda *et al.*, 2021). Therefore, the Mediterranean Diet is an excellent fit for the long-term plan to transition to sustainable production and consumption. In addition, olive oil is vital for the economic activity of the Mediterranean countries as well as the European Union in its entirety, since more than 33% of all EU farmers are olive oil producers. The EU is the biggest producer of olive oil in the world, whereby 67% of the world's olive oil is produced in European countries. Specifically, 95% of EU's olive oil production derives from Spain, Italy and Greece, making them the principal olive oil markets (European Commission, 2021a). Furthermore, the olive oil market has some other characteristics that make it worthy of further research such as the high degree of intra-trade activity within the EU, differentiation of this product in terms of different olive oil qualities, as well as market structure whereby the principal olive oil markets are characterised by high concentration of many small-scale olive oil units, while also bottling and processing is managed by few large-scale corporations (CBI, 2020). In terms of policy, the Common Agricultural Policy (CAP) has focused on sustainability and farmer support over the past couple of decades.

1.1.1 Types of Olive Oil

There are different types or grades of olive oil which are distinguished by their level of acidity, method of extraction and uses. According to the European Commission (2020a), olive oil can be distinguished in eight categories: extra virgin olive oil, virgin olive oil, virgin lampante olive oil, refined olive oil, olive oil composed of refined olive oil and virgin olive oils, olive pomace oil, crude olive-pomace oil, and refined olive pomace oil. However, the main types are extra virgin, virgin, pure and olive pomace olive oils. *Figure 1* presents the main differences between these types according to the IOC (2022b).



Author's Own (Data from IOC, 2022b)

Figure 1. Main Types of Olive Oil and characteristics

1.1.2 The key characteristics of the global market of olive oil

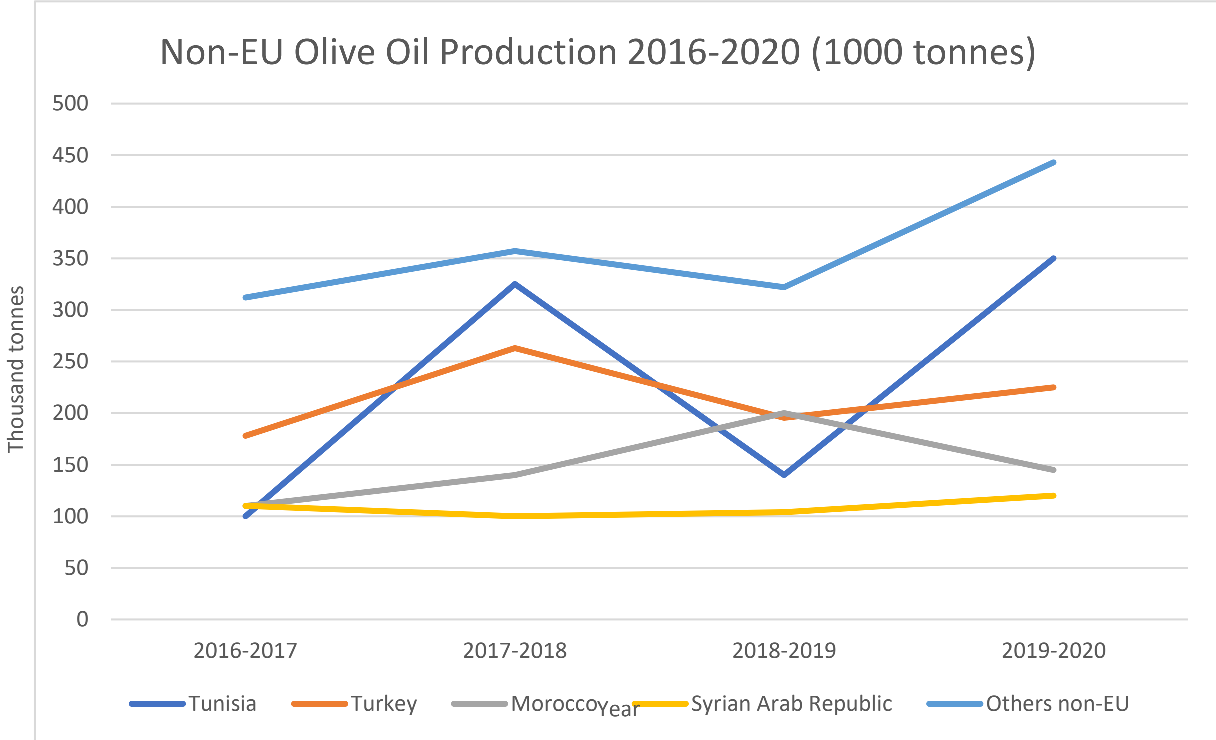
Olive oil is regarded as one of the most widely consumed and traded agricultural commodities across the globe (Buckland and Gonzalez, 2010). Its significance lies in its integral role in the Mediterranean diet and its strong connection to the economic development of countries that specialize in olive oil production and trade (Owen *et al.*, 2000). Olive oil world trade was valued at $376M in 2019 (OEC, 2020) and it is primarily reliant on the EU, since it constitutes the world's largest exporter (OOT, 2019a), producer and consumer of olive oil (European Commission, 2020a).

1.1.2.1 Production and Consumption

1.1.2.1.1 The Global Scene

Olive oil is produced globally, with Europe being the centre of global production. Specifically, global olive oil production tends to fluctuate around 3 million tonnes per annum, whereby approximately 2 million tonnes are produced in the EU (European Commission, 2020a). However, countries outside the EU such as Tunisia, Turkey, Morocco, and Syrian Arab Republic have shown substantial growth in the production of olive oil within the last 5 years, with 350 000 tonnes, 225 000 tonnes, 145 000 tonnes and

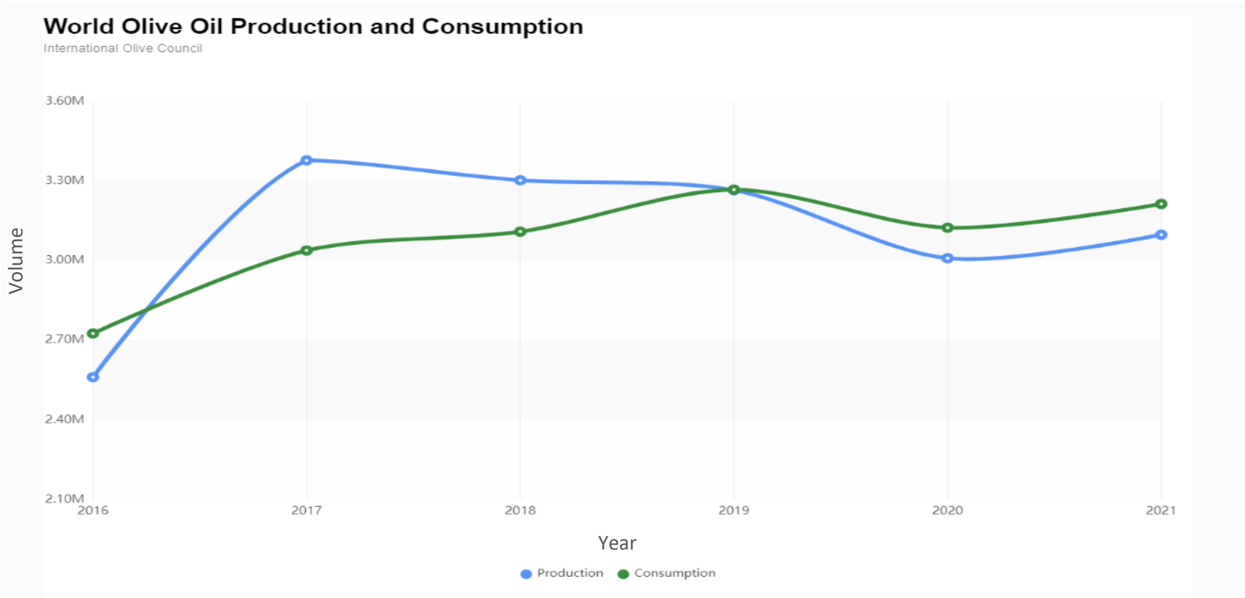
120 000 tonnes produced between 2019 and 2020, for each country respectively *(Figure 2).* In addition, 443 000 tons were produced in other non-EU countries for the same period.



Data from European Commission (2021c)

Figure 2. Non-EU Olive Oil Production 2016-2020

Consumption of olive oil has also exhibited a positive trend, globally, with the IOC (2022a) reporting that global olive oil consumption has doubled since 1990. In 2019-20, world olive oil consumption reached 3 268 500 tonnes, followed by a slight decrease to 3 174 000 tons in 2020-21. Consumption levels increased again in 2021-22, with 3 239 500 tonnes of olive oil consumed globally, and a minor decrease in consumption is expected in 2022-23, whereby consumption is currently forecasted at 3 055 000 tonnes (IOC, 2022a), which may be a result of rising prices. However, the IOC (2022a) recently highlighted the findings of new data that show global consumption of olive oil consistently remaining above global olive oil production; an unprecedent trend for three consecutive years (*Figure 3*). The Executive Director of the IOC has attributed this trend to the COVID-19 pandemic and how it has shifted consumers to healthier lifestyles and higher quality products (OOT, 2022b). Therefore, olive oil consumption is positively correlated to consumer health awareness and environmental factors which influence consumer purchasing habits.

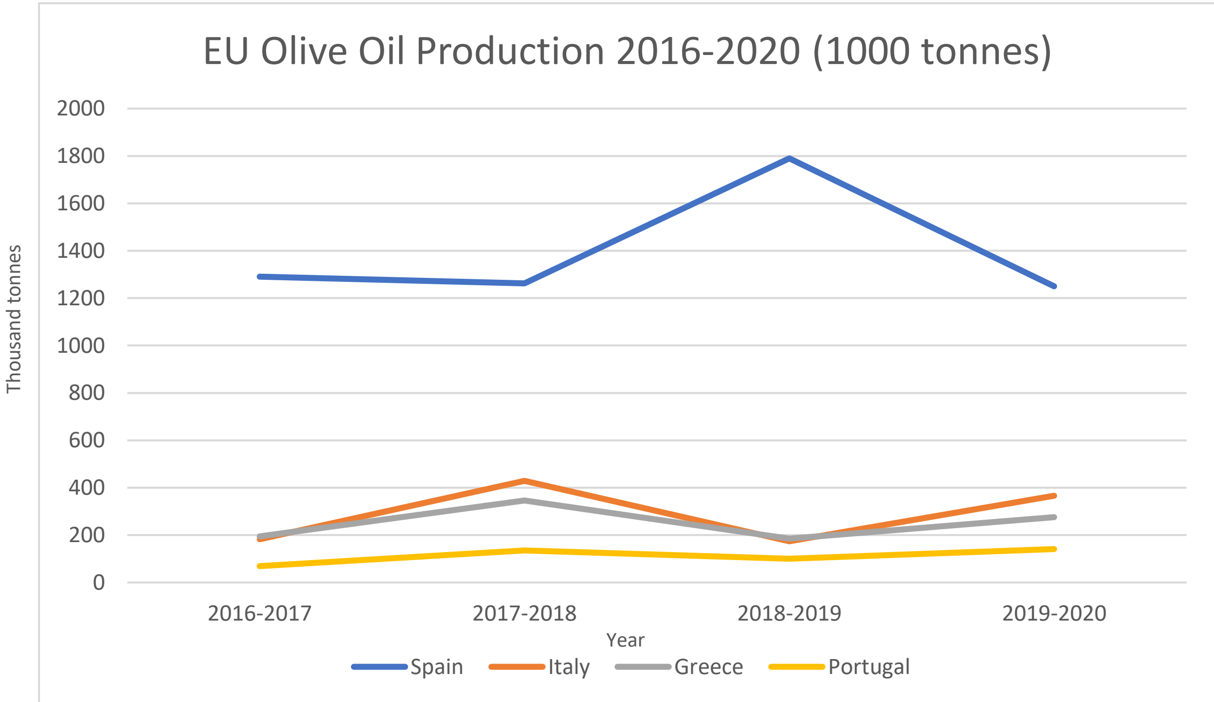


Source: OOT (2022b)

Figure 3. World Olive Oil Production against Consumption (2016-2021)

1.1.2.1.2 European Union

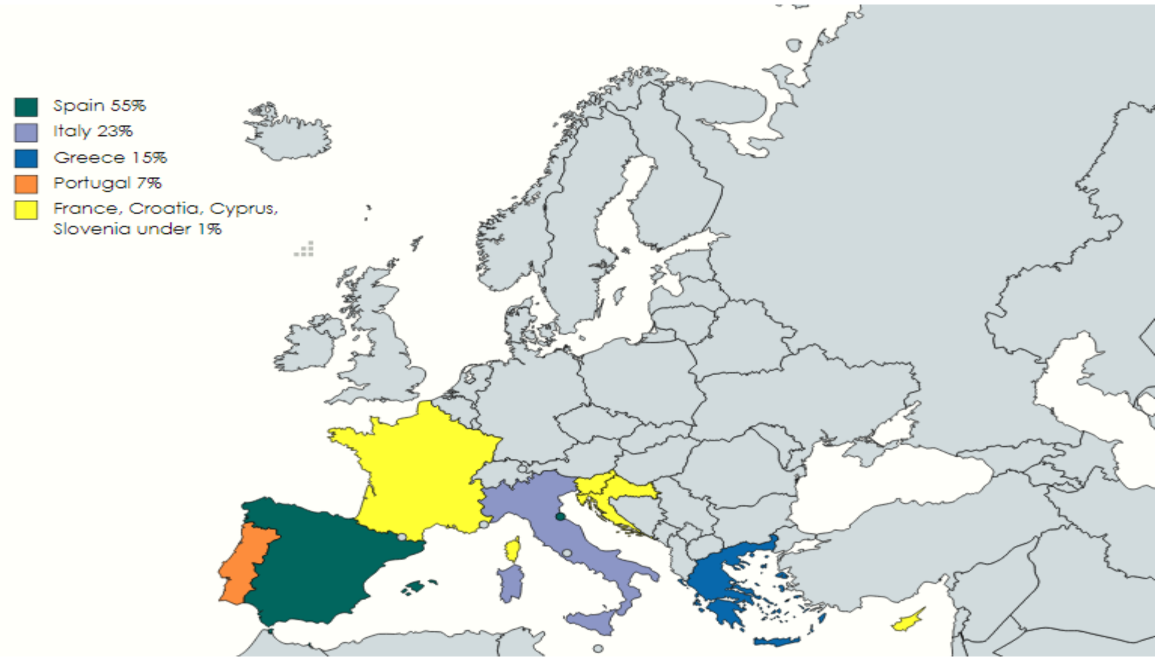
The EU is responsible for 67% of the global production of olive oil (European Commission, 2020b) and there is a total of 2.5m EU olive oil producers, which represent 33.3% of all EU farms (European Commission, 2002). EU olive oil production was relatively unstable between 2016 and 2020 *(Figure 4)*; however, the EU olive oil production reached 2,040,000 in 2020-21 and 2,270,000 in 2021-22 (Yawson, 2022). Despite this, the European Commission expects EU olive oil production to fall by 25% in 2022-23 (OOT, 2022d).



Data from European Commission (2021c)

Figure 4. EU Olive Oil Production 2016-2020

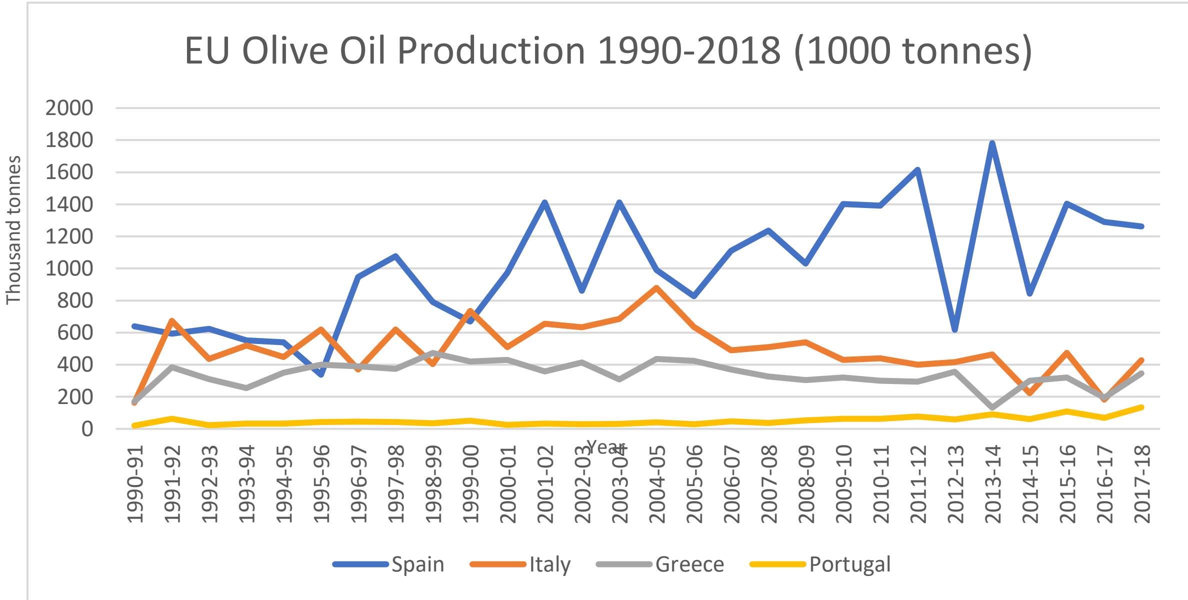
Olive trees are cultivated in Spain, Italy, Greece, Portugal, France, Cyprus, Croatia, Slovenia, and Malta (Rossi, 2017). The cultivation of olive trees covers an area of just under 5 million hectares (*Figure 5*) *(Eurostat, 2019).*



Data from Eurostat (2019)

Figure 5. Distribution of olive tree plantation area 2017

According to the International Olive Council (IOC) in 2020, Spain, Italy, and Greece are the primary producers of olive oil within the European Union. These countries collectively contribute over 60% to the world's olive oil production, with notable production from Bari in Italy, Chania in Greece, and Jaén in Spain (IOC, 2021). Regarding olive oil production, Spain has been the driving force since 2001 followed by Italy, Greece, and Portugal (IOC, 2020) *(Figure 6).*



Data from International Olive Council (2020)

Figure 6. EU Olive Oil Production 1990-2018

In particular, Spain produced over 1.7m tonnes in 2018/2019 which is the second highest amount since 2003 (OOT, 2019a) and it has accounted for 63% of the entire EU production on average from 2015 to 2018 (European Commission, 2020a). Then, Italy follows with 17%, Greece with 14% and Portugal with 5%. The production of these four countries combined, represent approximately 99% of the EU olive oil production, while about 95% of the EU production is concentrated in Spain, Italy, and Greece.

According to the IOC (2016), production in Spain, Italy and Greece accounted for 97.88% of the total olive oil production in the EU in the early 1990s. However, other smaller producers, such as Portugal started to increase their olive oil production. Specifically, Portugal recorded an increase of 545.5% in production over 25 years, dropping the production dynamic of the three principal EU olive oil markets to 94.57% in 2015-2016 (IOC, 2016). Noteworthy is also the increase in olive oil production in France with 500% over 25 years, although in total France accounts for under 1% of EU olive oil production (European Commission, 2021b). In general, the total EU olive oil production follows an upward trend over the last 30 years.

The EU is also the largest consumer of olive oil globally, with an estimated annual consumption of approximately 1.5 million tonnes of olive oil in European countries. This amount also accounts for 50% of the world's olive oil production, as reported by the European Commission (2020b). The majority of the olive oil consumed in the EU is attributed to Spain and Italy, with each country consuming approximately 500,000 tonnes per annum.

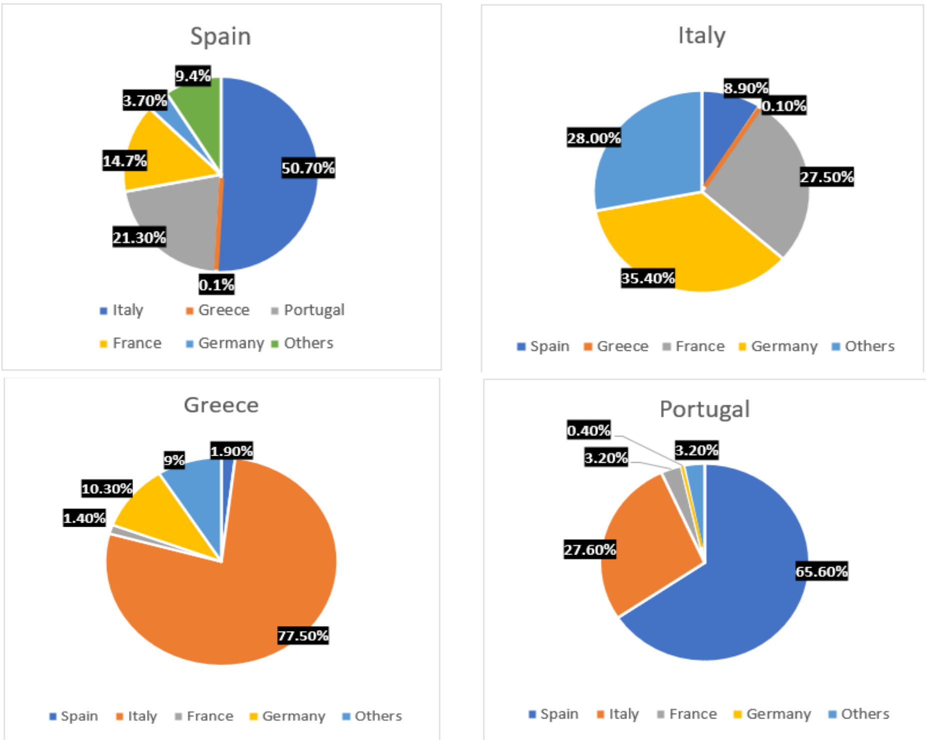
Despite this, the share of consumption of olive oil corresponding to the EU overall has decreased by approximately 20-25% since 2005 (IOC, 2022a). However, this decrease does not necessarily reflect the amount of olive oil consumed in EU countries, since it corresponds to the share of consumption that EU holds against other parts of the world, which have been increasing their consumption over time.

Nevertheless, rising olive oil prices seem to affect demand of olive oil in the EU. Specifically, the National Association of Industrial Packers and Refiners of Edible Oils (Anierac) in Spain and the Spanish Association of Olive Oil Exporters, Industry and Commerce (Asoliva) reported that olive oil prices at origin increased by 60% between 2021 and 2022 (OOT, 2022c). Similarly, the EC's market observatory noted an increase in olive oil prices at origin of 51% and 42% for Italy and Greece, respectively (OOT, 2022c). This has resulted in a gradual decrease in EU olive oil consumption over recent years. Particularly, EU olive oil consumption was reported at 1 520 100 tonnes in 2019-20, followed by a decrease to 1 474 800 tonnes in 2020-21. In 2021-22, an increase in consumption was recorded reaching 1 550 600 tonnes, however consumption is estimated to fall to 1 411 700 tonnes in 2022-23 (IOC, 2022a).

1.1.2.2 Trade

The EU constitutes the largest importing region in the world for olive oil, with imports accounting for over 50% of the global total. In addition, the majority of EU imports derive from other European countries. The EU also imports from non-European countries to the largest extent from developing countries; however, this accounts for only 12% of total EU imports. (CBI, 2020)

Figure 7 below shows the EU Intra-Trade share of olive in 2019-2020 for the most important players.



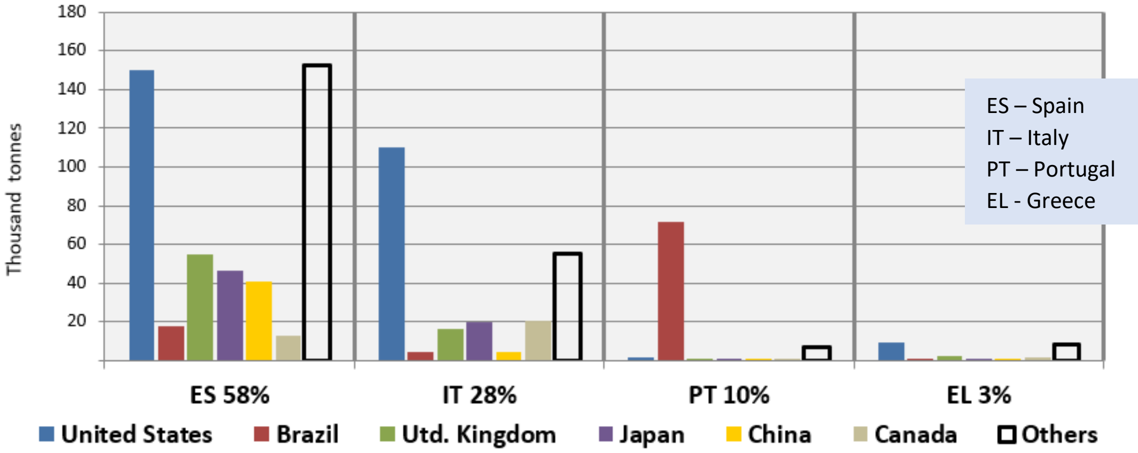
Data from European Commission (2021c)

Figure 7. EU Intra-Trade of Olive Oil (exports between European countries) 2019-2020

Italy holds a prominent position as the primary importer of olive oil within the EU, due to the fact that a majority of the intra-trade exports from Spain and Greece are primarily targeted towards Italy (Statista, 2020). Specifically, the total of intra-trade exports of Spain was recorded in 2019-2020 at 6,421,000 tons, 50.7% (3,256,000 tonnes) of which were exported to Italy, and only 0.1% (700 tonnes) was exported to Greece. Similarly, 77.5% of Greece's intra-trade is directed to Italy, whereas only 1.9% reaches the Spanish market. Italy's export levels, however, are mostly directed towards Germany with 35.4% (441,000 tonnes) of the total intra-trade exports, where only 8.9 (111,000 tonnes) and 0.1% (1,000 tonnes) are exported to Spain and Greece, respectively. (European Commission, 2021c)

Trade with countries outside the EU also plays an important role to the overall value of the global olive oil market. The total volume of olive oil exported from European to non-European countries was 820,670 tonnes in 2019-2020. The majority of these exports

(58%) derive from Spain, with the largest concentrated export volume being directed to the US (149,878 tonnes, 31.5%). The same applies for Italy and Greece, where 47.6% and 23.9% of their exports respectively are directed to the US. Finally, Portugal corresponds to 10% of olive oil exports to non-European countries, where 88.8% is exported to Brazil (CBI, 2020). *Figure 8* below shows the destination countries of of olive oil exports from the EU's olive oil key markets.



Source: Eurostat (2021)

Figure 8. EU Extra-Trade of Olive Oil (exports to non-European countries) 2019-2020

1.1.2.3 Market Structure

The global olive oil market exhibits a high level of market concentration, with six major organizations responsible for bottling over half of the world's olive oil production. In addition, due to high price competition large-scale production is taking over, leading to a decrease in small farmers and oil mills. Spain has around 1,800 olive mills, however these are owned by large companies such as Dcoop, which is the largest producer of olive oil in the world and Deoleo, the largest olive oil bottler globally. (CBI, 2020)

In contrast, the Italian olive oil market is composed of numerous small-scale olive mills, with the majority being family-owned businesses (European Commission, 2012). Although the production of Italian olive oil is primarily carried out by small-scale mills, larger-scale companies such as SALOV and Monini still dominate the market, as they are responsible for the storage, refining, and bottling of olive oil (CBI, 2020).

Similar to Italy, the Greek olive oil market is also made up of a large number of small farmers and olive mills, and 70% of these belong to co-ops that are controlled by Greek farmers (CBI, 2020). The biggest players in production and trade include Terra Creta, Nutria and Gaea. According to Mylonas (2015), while Greece ranks third in terms of global olive oil production, the country is renowned for producing superior quality olive oil in comparison to Italy and Spain. This is due to the fact that 80% of the total olive oil production in Greece is classified as extra virgin olive oil, in contrast to Italy and Spain, where only 65% and 30% of their olive oil production respectively is classified as extra virgin. Greece also has more olive varieties than anywhere else in the world and 60% of the land that is available for cultivation is devoted to olive cultivation (Prosodol, 2017). Despite the comparative advantages of Greek olive oil, such as its superior quality, Greece is not as prominent a player in the olive oil market as might be expected. According to industry data, only 27% of Greek olive oil produced reaches the branding stage of production, whereas 80% of Italian and 50% of Spanish olive oil reach this stage. Based on Mylonas (2015), this is mainly due to structural problems that force most of the olive oil that is produced in Greece to be sold in bulk to other countries, mainly Italy. This means that most Greek olive oil is in fact exported to Italy in bulk, to be branded and re-exported as Italian olive oil (Mylonas, 2015).

At the same time, Portugal has been increasing olive oil production gradually at 10% annual average rate in the last five years (European Commission, 2021b). However, it does not cause an immediate threat to the big players. According to CBI (2020), the construction of the Alqueva dam plays an important role in this continuous production growth in Portugal since it facilitates more regular irrigation. The olive oil market in Portugal consists of several cooperatives that were formed by local farmers. An example of such a cooperative is the Centre for the Study and Promotion of Alentejo Olive Oil (CEPPAL), which consists of 28 farmers. Apart from cooperatives, independent players stand out from the market, such as SOVENA.

Other European countries that cannot compete in terms of their production capabilities act as attractive consumer markets due to their unique characteristics. These are France, the United Kingdom, Germany, the Netherlands, Switzerland, and Belgium. It is worth mentioning that these countries do not only import from European countries, but also from developing countries. Imports from developing countries account for less than 10% in each case and important emerging suppliers include Tunisia and Turkey.

In France, the demand for olive oil cannot be met by local production; therefore, the country is considered as a growing consumer market (CBI, 2020). France holds the position of the third-largest importer of olive oil within the European Union. The majority of French imports of olive oil are sourced from Spain, followed by Italy and Tunisia (European Commission, 2021c). Studies conducted in France suggest that the type of olive oil is the most significant product attribute that affects consumer purchase decisions (Dekhili *et al.*, 2011). Specifically, the quality that is highly demanded by French consumers is extra virgin olive oil (Chrysochou *et al.*, 2022), which also corresponds to most imported olive oil volumes. The French olive oil market is mainly dominated by private labels with low profit margins, including brands such as Carapelli and Monini (CBI, 2020). Olive oil is primarily imported in bulk to France, while some of the leading olive oil brands are imported in bottled form (OOT, 2019b).

The olive oil consumption in the UK continues to increase at a steady rate, with an annual increase in imports of 5% recorded between 2015 and 2019 (CBI, 2020). In particular, in 2021, the value of olive oil imports to the UK was estimated at 170 million GBP, which translates to an approximate increase of 16% compared to the previous year (Statista, 2022b). As opposed to French imports, UK imports comprise mainly of standard olive oil, instead of extra virgin, virgin, or olive pomace oil. This market is relatively concentrated and heavily reliant on imports from Spain and Italy. The majority of imported olive oil is sold under the branding of major supermarket chains such as Tesco and Morrisons. (CBI, 2020)

Regarding Germany, over the last few years, there has been a shift of consumers' preference away from standard olive oil and towards extra virgin olive oil (Latino *et al.*, 2022). This is further supported by the fact that 76% of imported olive oil in 2019 was extra virgin olive oil (CBI, 2020). According to CBI (2020), Italy, Spain and Greece were the main suppliers of olive oil to Germany in 2019 in descending order, while Greece has been increasing extra virgin olive oil exports to Germany. For example, in 2017 a 33% increase was recorded of Greek extra virgin olive oil exports to Germany. As with the UK market, the majority of imported olive oil in Germany falls under private labels. Finally, as Germany has the highest retail sales for agricultural products of organic origin in the EU, Germany forms an attractive market to position for organic olive oil (Statista, 2022c).

Consumers in the Netherlands are shifting to healthier fats such as olive oil, which is evident in the decrease in butter and sunflower oil consumption and the gradual increase in olive oil consumption (OOT, 2022a). The decrease in sunflower oil consumption is also linked to the shortage of sunflower oil as a result of the ongoing war between Ukraine and Russia, which is another reason that Dutch consumers are seeking substitutes (CBI, 2022). Olive oil consumption in the Netherlands has recorded an annual increase of 10% on average in the last decade, despite the price sensitivity that characterizes Dutch consumers (CBI, 2020). Once again, over 50% of the olive oil imports are sold to private labels of large retail chains such as Aldi and Lidl (CBI, 2020).

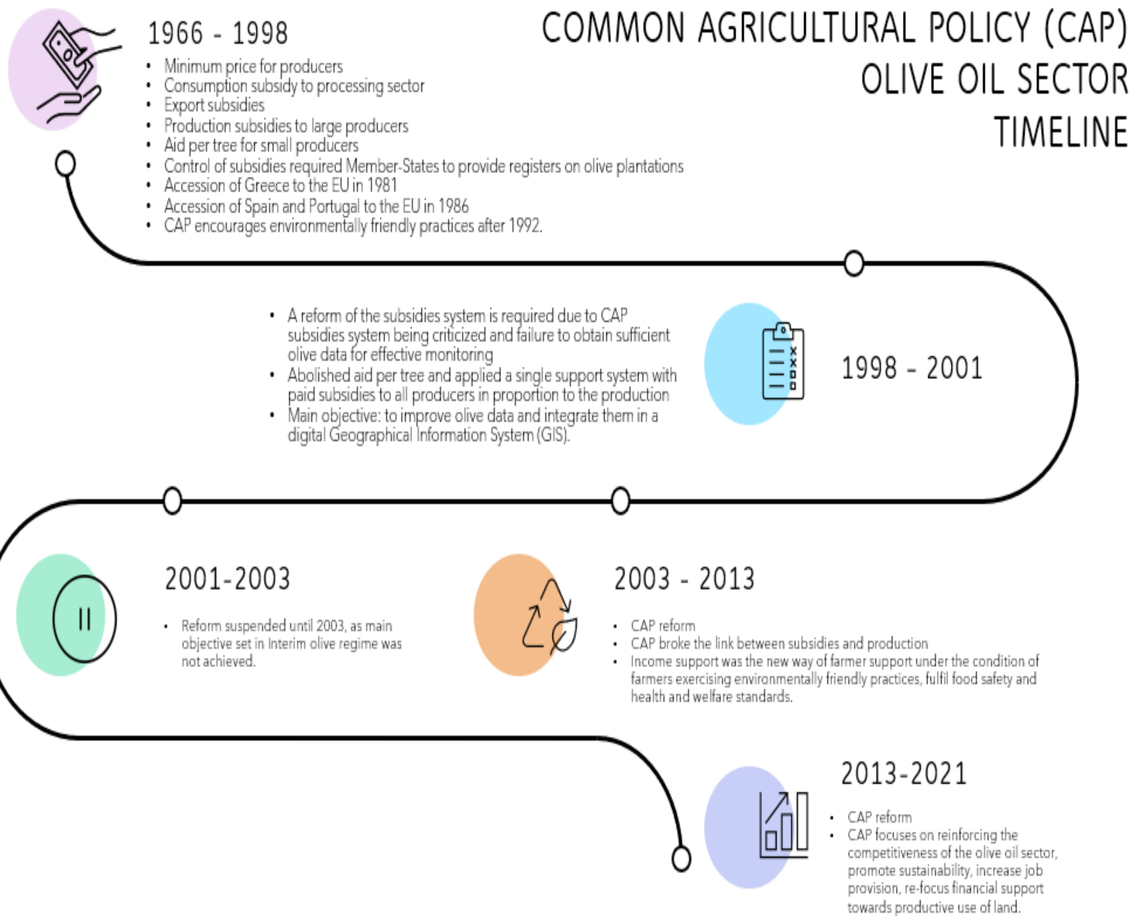
Olive oil imports in Switzerland have been constantly rising since 1992, with a steadier growth recorded between 2005 and 2018 (IndexMundi, 2021), making Switzerland a promising market for future trade. An annual growth of 2% in olive oil imports is noted reaching 15,000 tonnes in 2019 and most of the imports represented olive oil sold in bulk form to private labels in Switzerland like Coop and Migros (CBI, 2020). In contrast to other European markets, Switzerland's olive oil imports are primarily sourced from Italy (47%), followed by Spain (32%). Additionally, consumers in Switzerland have shown an increasing interest in organic olive oil (CBI, 2020).

Lastly, Belgium's olive oil imports have been experiencing growth, especially in the category of extra virgin olive oil (IndexMundi, 2021). There is also a rising demand for organic olive oil among Belgian consumers. The country primarily imports olive oil from Spain and Italy, but there has been a 300% increase in imports from Greece between 2015 and 2019 (CBI, 2020). The majority of olive oil imports comes in bulk and 26% of the total amount imported in Belgium is re-exported (CBI, 2020).

1.1.3 Common Agricultural Policy

The Common Agricultural Policy (CAP) is a policy of the European Union that aims to support EU farmers financially, protect rural areas, and promote the overall economy. It was first introduced in 1962 and has since undergone several reforms. Article 39 of the Treaty on the Functioning of the European Union outlines the objectives of the CAP, which include increasing agricultural productivity, ensuring a good standard of living for farmers, stabilising markets, ensuring availability of food supplies, and maintaining reasonable prices for consumers (Parrock and Huet, 2020).

Regarding olive oil, CAP has always played an instrumental role by introducing several policy interventions and shielding structures to protect the EU market and farmers *(Figure 9)*.



Author's Own (Data from European Commission, 2021b)

Figure 9. CAP Timeline with key facts relating to the olive oil sector

The first subsidies were given to EU olive oil farmers in 1966 with the EU Regulation 133/66/EEC. This measure was introduced to protect EU producers, such as Italy, from external cheaper imports such as from Tunisia and Morocco. At the time, CAP mainly focused on offering production and export subsidies to increase olive oil productivity and competitiveness. Moreover, it was consumption-oriented, aiming to make domestic olive oil more attractive to consumers than olive oil imports.

The EU olive oil became competitive after 1981 and 1986 when Greece and Spain respectively joined the EU; thus, turning it into the largest olive oil exporter (Leguen de Lacroix, 2002). According to Chousou (2020), total subsidies increased by 333% between the periods 1980-1985 and 1991-1996, which reflects the substantial increase in olive oil production and subsidies given, after the accession of Greece, Spain, and Portugal to the EU in the 1980s (European Commission, 1997).

Between 1966 and 1998, CAP aimed towards a fixed minimum price for producers, consumption subsidies offered to the processing sector, export and production subsidies and financial aid per tree. The financial aid varied according to producer farm size. Large producers were considered those who produced more than 500kg of olive oil per annum, whereas small producers were the ones who achieved less than 500kgs of production.

A subsidy based on the production was given to large producers, while an aid per tree was given to small producers based on the recorded average values regarding past yields of their region. In addition, for monitoring purposes and control over subsidies, the CAP required member-states to submit registers on their olive oil plantations. The CAP system was initially structured to offer income support to farmers based on the olive oil produced. However, this incentive led to overproduction, especially after the accession of Greece and Spain to the EU - the largest producers, which, in turn, resulted in negative environmental consequences. A surplus in production was not the case only for olive oil but represented the broader situation regarding the EU agricultural commodities (European Commission, 2021a).

The CAP system was widely criticised, which led to multiple reforms in the following decades. As a response to overproduction, new measures were introduced to achieve equilibrium between demand and supply, such as the Maximum Guaranteed Quantity (MGQ).

An interim olive regime followed between 1998 and 2001 with Regulation 1638/1998, when a reform of the subsidies system was required since member-states failed to provide registers on their olive plantations (Tropea, 2016). Another reason for the reform was that the subsidies system was based on olives and not oil produced (Chousou, 2020). During this reform, the aid per tree was replaced with a single support system with paid subsidies to all producers in direct proportion to the production, and MGQ increased by

132%. The primary purpose of this interim olive regime was to improve olive data and integrate them into digital Geographical Information (GIS).

In 2003 reform, the CAP switches from subsidies linked to production to farmers income support, which they would receive on the condition that their farming practices would meet food safety, environmental, health and welfare standards (European Commission, 2021b).- 2008 Health Check - The CAP lens changes focus in 2013 through a reform that aimed to strengthen competitiveness for the sector while promoting sustainable farming practices, facilitating employment growth in the sector, and providing financial aid to encourage rural development (Tropea, 2016). The new rules were in force during the period 2014 to 2020.

During this period, CAP had six targeted areas. According to Juan (2014), these areas included the International Olive Oil Council (IOOC), industry structure, quality control procedures and authenticity criteria, promotion, restructuring the olive oil sector and competition with third countries. Under CAP, the IOOC is a pivotal element to the growth of the olive oil sector. The IOOC plays a crucial role in the growth of the olive oil sector under the Common Agricultural Policy (CAP). Its primary responsibility is to promote and facilitate improved product quality and increase demand for products originating from the olive tree. The IOOC provides intensive support through marketing campaigns aimed at promoting the unique benefits and properties of olive oil to consumers. The second area of CAP reform involved the industry structure, where support was provided to groups of producers and regarding the marketing of the products. In terms of the consumer side, CAP also considers consumer protection. Therefore, the third targeted area involves improving labelling and higher quality control standards and authenticity criteria. While part of the IOOC responsibilities entails promoting the benefits of olive oil to increase consumer demand, CAP dedicates an entire area on promotion to address the imbalance between EU olive oil supply and EU olive oil demand (EU Supply > EU Demand). Another targeted area under the 2014-2020 CAP Reform focuses on stimulating investments for olive oil processing, while the last area targets competition with third countries.

Moreover, one of the significant changes introduced in the latest CAP reform is the switch to the single payment scheme, which consists of seven elements. According to Chousou (2020), while the first three are obligatory for all EU member states, the remaining four are optional. These elements include basic payment per hectare which serves as a fundamental means of furnishing income support to producers, additional support to encourage the use of environmentally friendly farming practices, additional financial aid for young farmers to support their income, additional income aid to farmers who use farming areas with natural constraints, production support for specific farming methods, and a simplified payment system for small producers.

With the latest CAP reform period ending, an interim regulation is currently in force during 2021-22 to ensure a smooth transition to the future CAP strategy. Most of the latest CAP rules are extended during this transitional period until the following CAP legal framework, which is expected to be implemented from 1 January 2023 (European Commission, 2021b). The future of the CAP moves towards a simpler and more efficient direction that will encompass the sustainable aspirations of the European Green Deal, placing the EU farmers in the centre of halting climate change, safeguard the environment, and turn to more sustainable and resilient food structures (European Commission, 2020b). According to the European Commission (2020b), the new CAP budget has been agreed at 387 billion euros over seven years.

Considering the importance of this sector, studying the principal olive oil markets regarding the degree of price dependence is crucial to enable effective policy decision making and inform further reforms that will help strengthen the olive oil sector in international markets. Based on the information provided in the Global Olive Oil Market section, it is expected that the EU olive oil market will be characterised as inefficient due to asymmetries in the price transmission process. This is evident by the differences in the production systems and capacities that each country operates, as well as the different structure of the market within each country. In particular, Spain has few large olive oil producer companies, whereas Italy and Greece have many small-scale family-owned mills and farmers cooperatives, respectively. In addition, olive oil has different qualities which constitute different products. Therefore, differences in consumer preferences may also lead to inefficiencies. Furthermore, information on EU intra-trade activity demonstrates a closer and more active trading relationship between Greece and Italy, which may infer a higher degree of market integration between the two. However, Italy as the main EU olive oil importer, also undertakes the bottling and branding of imported olive oil, which gives an advantage over the other players, suggesting the presence of market power. In this respect, asymmetries may disrupt the price transmission process. Moreover, information on past CAP reforms highlight the efforts of the EU to address inefficiencies in the EU olive oil market and strengthen competition through incentives including technological advancements, sustainable practices, and more. Although, this allows the three main production countries to balance the differences within their technological and production capacities, intense government intervention through CAP reforms may impede the smooth price transmission process. This highlights the significant impact of CAP in the EU olive oil market, which is expected to appear in the price transmission mechanism in the form of structural breaks. Overall, based on the Global Olive oil market section of this study, it is expected that the EU olive oil market will be integrated, however the extent of market integration between players will differ. Despite the EU olive oil market being integrated, asymmetries are expected in the price transmission process, suggesting that the market is inefficient.

Although olive oil is a key commodity due to the characteristics mentioned above, only a limited body of literature has investigated price relationships within Mediterranean countries, with a particular emphasis on olive oil prices (Fousekis and Klonaris, 2002; Emmanouilides *et al.*, 2014; Panagiotou, 2015). Nonetheless, these studies yield mixed results regarding the extent of market integration in these markets. Moreover, research investigating spatial price dynamics in agricultural commodity markets typically neglects the possibility of structural breaks, that could impact the price transmission mechanism and relies heavily on linear methodologies. A major concern, though, pertains to the potential nonlinearity of spatial price dynamics, frequently ascribed to imperfect arbitrage caused by transactional costs and uncertainty (Serra *et al.*, 2006b). However, when these are considered, the analysis is performed primarily in different systems, thus leading to information loss. This highlights the need for studies that will explore short and long-run nonlinear price relations under a single system, considering structural breaks.

1.2 Study Contribution

The originality of this study is based on examining long-run price relations under a single system and accounting for breaks and nonlinearities generated from transaction costs (Serra *et al.,* 2006b), using the nonlinear Asymmetric Autoregressive Distributed Lag (NARDL) technique (Shin *et al.*, 2014). Additionally, the leadership in price formation will be explored through the nonlinear Diks and Panchenko (2006; 2013) causality test. More recent data will also be used compared to previous studies, thus reflecting the potential impact of the last CAP reform (2013-2021) on the olive oil sector. This is particularly important since any significant changes in the CAP, during this period, that affects the olive oil markets can be expressed in the form of structural breaks allowing the evaluating their impact the price transmission process and potentially the efficiency of the markets. The last CAP reform entailed a shift in focus from supporting farmers to strengthening the sector and promoting sustainability. In addition, significant recent events such as the COVID-19 pandemic and the energy crisis can lead to further reforms to safeguard the EU agricultural markets, thus affect the price transmission mechanism. Furthermore, this study will take a mixed method approach to analyse the price transmission process, by using both qualitative and quantitative techniques and thus triangulation of methods will be employed. While the majority of studies examine price transmission using quantitative methods, there are only two studies that have used both qualitative and quantitative tools. Specifically, Aragrande *et al.* (2017) analysed vertical price transmission in the sugar market, and Acosta *et al.* (2019) investigated price transmission in the milk market. As a result, this study will contribute to literature around price transmission analysis in agricultural commodity markets and specifically olive oil.

1.3 Research aims and objectives

Therefore, this thesis will examine price linkages in the three principal olive oil markets in the EU through an empirical analysis. In particular the present study will aim to explore the following research objectives:

1. Collate and analyse evidence of price dependence in the EU edible oil markets focusing on olive oil markets.

2. Examine the degree of market integration in the principal virgin and extra virgin olive oil markets in the EU.

3. Analyse the long-run relations between the principal virgin and extra virgin olive oil markets in the EU and the adjustment process to long-run and short run equilibrium.

4. Determine the pattern of price transmission in the principal virgin and extra virgin olive oil markets in the EU.

5. Investigate the efficiency of the principal virgin and extra virgin olive oil markets in the EU.

1.4 Structure of the thesis

To examine these research objectives, the present study is structured as follows.

Chapter Two will present the key theoretical concepts that underpin this research. Specifically, the terms market integration, the Law of One Price, price transmission, price volatility transmission, asymmetric price transmission and the causes of asymmetry will be explained. A review of the existing literature will be carried out, which will be classified in studies that have investigated horizontal, spatial, and vertical price transmission, studies focusing on edible oils and studies related to olive oil. This will be followed by a systematic map which will explore existing literature in a structured way through mapping relevant studies and collating the findings. Specifically, the systematic map will examine evidence of price dependence in EU edible oil markets including olive oil markets. Through this, the research gap for studies that investigate price transmission in EU olive oil markets will be established and highlighted, forming in this way further justification to extend the research in this field. This chapter will also provide valuable insight into the price relations within other edible oil markets in the EU, providing further understanding of the possible causes of asymmetries, thus informing further policy implications that may also apply in the case of olive oil. ***(OBJECTIVE ONE)***

Chapter Three will present the conceptual framework of this research, which will explain the rationale for this study, how the methodology was formulated and the expected outcomes.

Chapter Four will showcase an econometric analysis of price linkages in the principal EU olive oil markets; namely, Spain, Italy, and Greece. Prices of the two highest qualities of olive oil will be analysed in two distinct sub-sections: one dedicated to virgin and the other to extra virgin olive oil. The purpose will be to assess the degree of market integration ***(OBJECTIVE TWO)***, causality relations among the major players and the long and short-run relations ***(OBJECTIVE THREE)***. Furthermore, Possible asymmetries in the long and short-run relations between the examined markets will also be investigated, including structural breaks in the price pattern ***(OBJECTIVE FOUR)***, as well as the validity of the Law of One Price will determine the efficiency of the market ***(OBJECTIVE FIVE)***. Then, the findings from the empirical analysis of each olive oil quality will be summarised and discussed.

Finally, Chapter Five will present the main conclusions and policy implications resulting from this analysis. In addition, study limitations will be determined providing areas for further research.

Chapter 2 Literature Review

This section will introduce the key theoretical concepts that underpin this research. The concepts of Market Integration, Spatial market integration, Spatial arbitrage, and the Law of One Price will be introduced. Moreover, price Transmission, Price Volatility Transmission and Asymmetric Price Transmission will be explained along with possible Causes of Asymmetric Price Transmission. Furthermore, previous studies that have examined price transmission in agricultural commodity markets will be presented and discussed along with studies that have investigated the price transmission process in edible oil markets through a systematic map.

2.1 Theoretical Framework

2.1.1 Market Integration

Market integration has become a significant focus of policymakers and researchers in recent years, as it has a notable impact on the functioning of a market economy. Market integration is always related to market efficiency, offering insight into the performance of key players and their relationships.

It is essential in this sense to monitor indicators for market efficiency as this will form the foundation to trigger the change that will ensure economic welfare is equally distributed among stakeholders. In this line, Pelkmans *et al.* (2014) have characterised monitoring indicators for market efficiency as the atlases of the policy and economic world.

According to Monke and Petzel (1984), an integrated market refers to a market where the prices of homogeneous products are interdependent. Similarly, Faminow and Benson (1990) defined integrated markets as markets where the prices of identical products exhibit interdependence, implying that a change in the price of a product in one market will affect the prices of the same product in other markets.

Existing literature suggests four dimensions of market integration: goods, services, capital, and labour (Bublitz, 2018). Most analyses in the EU focus on goods markets as these are the most integrated ones, according to Guimaraes *et al.* (2010). The EU has been utilising market integration as a key European policy over time, and it is recognised that the principles of the CAP have been designed to ensure the integration of individual agri-food markets in the European area by promoting free trade and defining a common external pricing policy. During this process, however, significant barriers to integration endured in many countries for various reasons, such as the lack of adequate arbitrage mechanisms between markets and member states and imperfect competition (Zanias, 1993).

At the same time, the integration of markets is gradually being undertaken on an international, transnational, and regional level on a global scale, as this is essential for economic growth, given that in a perfectly integrated market, producers base their decisions on market price information, leading to a balanced allocation of resources (Goodwin and Schroeder, 1991). In general terms, markets are considered to be integrated when linked to a process of effective arbitrage, as reflected in the values of a series of basic products in spatially separated markets (Lele, 1967). Hence, the comovement of the price of homogeneous goods in geographically separated areas is the main measure to determine the degree of market integration (Goodwin and Djunaidi, 2000). The movement and reaction in prices are referred to as price transmission. Researchers focus on the level and the mechanisms of price transmission to conclude the degree of integration of the examined markets.

Access to reliable and comprehensive information regarding market integration is crucial, as it provides valuable insights into market competitiveness, arbitrage effectiveness (Buccola, 1983), and pricing efficiency (Carter and Hamilton, 1989). High quality information is only available if there is a high degree of price transmission. Sometimes, however, trade policy or transaction costs caused by the deficiency or absence of physical and communication infrastructure result in a low degree of price transmission, reducing the price information available to economic agents. Therefore, the incomplete information can potentially lead to inefficient market outcomes. Arguable concepts like trade liberalisation and the way costs and benefits are distributed across societies are profoundly affected by the degree to which markets are integrated. Hence, economists stress the importance that the price transmission theory is accurately understood to achieve the desired outcome, which is effective policy.

Among the researchers that place particular weight on the importance of achieving market integration, Baldwin and Venables (1995) and Pelkmans (2006) focus on the outcomes from market integration. First, it leads to a reduction of trade costs, which results in an increase in new trade flows and higher benefits from existing trade streams. It also promotes variation in the external competitiveness of the regional bloc, increasing the level of competition which leads to a reduction in price-cost margins. Market integration increases product variety, eliminates technical inefficiencies, and reduces the cost of production, thus creating economies of scale.

The topic of the EU market integration was the focus of early studies, such as Zanias (1993). Studies have turned to examine integration between the EU and the world markets in recent years, such as Mela and Canali (2012) and in developing countries, like the study from Baquedano *et al.* (2011). The liberalisation of agricultural trade policies has been a key objective for many developing countries, with the aim of integrating their agricultural economies into the global market and reaping the potential benefits of specialisation and trade based on comparative advantage. Increased competition resulting from trade liberalisation can lead to some companies exiting the market while others expand production, taking advantage of economies of scale (Serrano *et al.*, 2015).

2.1.1.1 Spatial market integration, Spatial arbitrage, and the Law of One Price (LOP)

To achieve successful market integration, a high transmission or pass-through of world price signals to domestic producers and consumers is crucial. Therefore, high degree of price transmission suggests market integration thus market efficiency.

To achieve market efficiency, the price pass-through between markets needs to be complete (Ardeni, 1989). When goods and information are transmitted freely between geographically separated markets, which implies a well-functioning market, spatial arbitrage activities ensure that the difference in the prices of a homogenous product in two separate locations will differ by no more than the transaction cost (Fackler and Goodwin, 2001).

$$p^j - p^i \leq r^{ij} \qquad (3.1)$$

where p^j represents the price of a commodity in the market with the higher price, p^i represents the price of the same commodity in the market with the lower price, and r^{ij} represents the transaction cost associated with moving the product from one market to the other also accounting for the transport costs.

Therefore, the majority of empirical studies that analyse spatial price transmission test the validity of the law of one price (LOP) (Listorti and Esposti, 2012). The LOP states that identical goods traded in different locations should sell for the same price once they are converted to the same currency (Lee, 2008):

$$P^n = EP^{*n} \qquad (3.2)$$

where P^n represents the domestic currency price of a product, E is the domestic currency price of exchange rate, and P^{*n} is the foreign currency price of a product.

This can also be referred to as the absolute or the strong version of the LOP since it implies that prices move perfectly together over time:

$$p_t^i = p_t^j + \varepsilon_t \qquad (3.3)$$

where p_t^i is the price at every moment in time of a commodity in one market, p_t^j is the price at every moment in time of the same commodity in another market, and ε_t is a zero-mean stationary error term. This suggests that prices are expected to be equal at any moment in time, regardless of the past and current price levels.

However, the relative version of the LOP, also known as the weak version, suggests that the LOP holds when the differences in prices can be described as stationary, meaning that they are not moving (Froot and Rogoff, 1995; Sarno and Taylor, 2002):

$$p_t^i = p_t^j + \beta + \varepsilon_t \qquad (3.4)$$

where $\beta \neq 0$ is a constant and ε_t is a zero-mean stationary error term. This implies that prices are expected to differ by β regardless of the past and current price levels.

If the spatial arbitrage condition does not apply, in other words if the difference between prices in different markets exceeds the transaction costs, then arbitrageurs would immediately exploit this opportunity for profit. Therefore, prices in integrated markets are expected to move together (Sarris and Hallam, 2006) and the LOP should hold, at least in its weak form. Otherwise, this would be an indication that opportunities deriving from arbitrage are not fully considered, which leads to welfare losses.

The LOP has been examined in different agricultural commodity markets over the years to understand the spatial market linkages between the examined markets. Baffes (1991) tested for the LOP for wheat, tea, beef, sugar, wool, zinc and tin, in the United States, Canada, Australia and the UK markets. This study found mixed results in terms of the LOP, since the LOP was found to hold for some of these markets, while in the markets that the LOP was rejected, this was attributed to transportation costs. Similar results were found Yang *et al.* (2000) who also confirmed the validity of the LOP in soybean meal markets between developed countries (United States and United Kingdom) and developing countries (Argentina and Brazil). On the contrary, Fousekis (2007) rejected the LOP within the EU for pork and poultry markets, where the LOP does not hold due to collusive behaviour that may exist in these markets. In contrast, a couple of years later Emmanouilides and Fousekis (2012) found that the LOP holds for all pairs examined for pork markets between Germany, Spain, France and Denmark and specifically for the pair Germany-Spain the LOP holds in its strong version. This may be explained by the fact that Germany and Spain are the two largest producers of pork meat in the EU. The difference in the results of Fousekis (2007) and Emmanouilides and Fousekis (2012) in terms of the LOP, may be due to different methodologies utilised. Another study that has tested for the LOP found that the LOP does not hold between pig and beef meats markets in the Czech Republic (Rumánková, 2012); however, evidence from the same study suggests that if transaction costs are excluded, the findings regarding the validity of the LOP in different regions of the Czech Republic may differ. These results are in line with Muwanga and Snyder (1997) for cattle markets in 12 US regions. The LOP was rejected in the majority of the market areas that were examined in this study and this was credited to lack of current information or lack of access. In terms of other commodity markets, Gobillon and Wolff (2016) examined the validity of the LOP in French fish markets and their findings indicate that the absolute LOP does not hold for most of the studied fish species when considering local fish markets. However, the findings from this study may be biased due to disregarded heterogeneity of the fish products; fish markets in France are located on two separate costs, namely the Atlantic and the Mediterranean. This means that the fish markets considered in this study may not represent homogenous products.

2.1.2 Price Transmission

Price transmission refers to the process by which shocks in the prices are transmitted from one market to another (McCorriston, 2015). Relevant existing literature has been examining the topic of price transmission for several decades. It is widely used as an analytical tool to assess the functionality and flexibility of markets and the mechanisms that frame them. Goundan and Tankari (2016) identified the factors that influence the degree of price transmission. According to their research, price transmission is affected by trade policies, transaction costs, trade flows and availability of price information and infrastructure. A close analysis of these factors forms a strong basis for decision making.

In general terms, when markets are effective and the relevant policies do not interfere with the orderly and smooth function of the markets, changes in the price of a particular commodity in the global market should be reflected proportionally to the domestic prices. This is the definition for price transmission as per Keats *et al.* (2010). There are two types of price transmission: vertical and horizontal.

Price transmission in its vertical form refers to the price movements across the levels of the supply chain of any given commodity, from the producer to wholesale and retail levels, and vice versa. Vertical price transmission has attracted strong interest from researchers for several reasons. Firstly, it provides valuable information about the bargaining power of the different trading parties in the market, which explains the possible relationships that are developed in later stages of the trading environment. Secondly, it helps to understand the impact of any applied policy reforms (Falkowski, 2010). Finally, studies focusing on the analysis of vertical price relationships form a robust foundation to understand the causes of any conflicts between individual levels of the supply chain.

Price transmission in its horizontal (or spatial) form mainly refers to the price relationships between geographically separated markets. However, the wider meaning of horizontal price transmission includes also the indirect horizontal form, which considers the transmission of prices for goods designated as substitute or complementary (Areté, 2012). Based on Listorti and Esposti (2012), indirect price transmission can be categorised in the price transmission between a) different agricultural commodities, b) agricultural and non-agricultural commodities, and c) individual future contracts for the sale of the same commodity (Alam *et al.*, 2010). Consequently, horizontal price transmission examines price relationships of different markets at a specific level of the supply chain. Spatial price transmission describes the pass-through of price signals between countries that are trading the same agricultural commodity, from the central market, which is also the price leader, to the price followers.

A necessary condition for price transmission is the presence of trade between countries. Price changes between different markets have significant implications both to consumers' and producers' welfare. Therefore, investigating spatial price transmission is of great importance for policymakers and economists in agriculture (Sexton and Lavoie, 2001). According to Emmanouilides and Fousekis (2012), spatial price relationships reveal the performance of the markets. In this sense, smooth price transmission is an indication that markets are well-integrated, whereas incomplete price transmission implies market segmentation.

2.1.3 Price Transmission and Price Volatility Transmission

Researchers have extensively analysed price transmission in food and energy markets; however, price volatility has not attracted much attention (Abdelradi and Serra, 2015a; 2015b). While price transmission signifies spillover in the mean of price changes between markets, price volatility transmission reflects the spillover of price variance in the markets (Rapsomanikis and Mugera, 2011; Bergmann *et al.*, 2016). In addition, Assefa *et al*. (2016) provides further insight by suggesting that price transmission pertains to predictable price segments, whereas price volatility spillover pertains to unpredictable price components. Therefore, while both concepts are used to examine price relations, they differ in their respective focus on distinct aspects of prices (Bergmann *et al.*, 2016)

A study by Bergmann *et al.* (2016) highlights the importance of analysing both price transmission and price volatility transmission. This is also supported by Rapsomanikis and Mugera (2011), who emphasise that it is essential to consider both concepts to get an integrated and complete understanding of price relationships/linkages, and therefore contributing to more effective policy formulation.

2.1.4 Asymmetric Price Transmission

The foundations of market integration and full price transmission are aligned with the foundations of the standard competition model. In other words, in an ideal world the Law of One Price will hold so that it regulates spatial price relations, while vertical price relations will depend exclusively on production costs (Fackler and Goodwin, 2001). However, the agri-food sector is highly characterised by asymmetries in price transmission. Peltzman (2000) reported that 42% of agricultural and food commodities experience Asymmetric Price Transmission (APT). This means that the price pass-through is imperfect and output prices respond slower to input price decreases than increases (Bakucs *et al.*, 2013).

Asymmetry by definition refers to a disproportion or anomaly in the movement of a flow, so it would be expected that asymmetry is not the norm in price transmission. However, Peltzman (2000) presented compelling evidence suggesting that asymmetric price transmission is a common occurrence rather than an exceptional phenomenon. This conclusion was drawn following an extensive analysis of 282 products, of which 120 were agricultural commodities. Meyer and von Cramon-Taubadel (2004) also reached similar conclusions, even though other studies (Gauthier and Zapata, 2001; von Cramon-Taubadel and Meyer, 2000) question whether such conclusions may relate to issues in the utilised methodologies.

Meyer and von Cramon-Taubadel (2004) stressed the importance of acknowledging the presence of asymmetries in price transmission for policymakers, since it reflects price inefficiencies and can be a sign of market failure. Asymmetric Price Transmission can lead to ineffective allocation of resources and distributing output which will have a major impact on welfare distribution and implications on policy. In the agri-food market, positive asymmetries indicate that consumers experience a welfare loss, as they benefit less from a decrease in the price of agri-food commodities compared to an increase in prices. Conversely, negative asymmetries suggest that farmers experience a welfare loss, as they cannot benefit to the same extent from price increases as they lose from price decreases. This is due to the fact that changes in upstream and downstream prices do not move proportionally. According to Tvrdoň (1992), agricultural markets are subjected to high degree of policy intervention and are relatively inefficient compared to non-agricultural markets, which makes it difficult to achieve and preserve increases in the income of farmers due to policy constraints on increasing prices of agricultural commodities. Policy measures aimed at reducing farm prices do not always result in corresponding decreases in consumer prices, indicating that such measures may not be sufficient.

Researchers analyse different aspects of asymmetry in their attempt to achieve better understanding of price movements. According to Meyer and von Cramon-Taubadel (2004), asymmetry in price transmission can be classified in terms of the nature of asymmetry, the magnitude or speed of price transmission, and direction. The nature of asymmetry refers to positive or negative asymmetry. While Peltzman (2000) was the first to describe this concept, Meyer and von Cramon-Taubadel (2004) have explained this as follows. If p^{out} responds quicker or more fully to an increase in p^{in} than a decrease, then the asymmetry is defined as positive asymmetry (*Figure 10*). In the same respect, if p^{out} reacts quicker or more fully to a decrease in p^{in} compared to an increase, then the asymmetry is described as negative asymmetry (*Figure 11*). This provides an important measure for the examination of welfare distribution between all involved stakeholders. For instance, if we assume in a vertical context that p^{in} represents wholesale prices and p^{out}

accounts for retailer prices of a commodity, we can deduce that a positive asymmetry will benefit producers and harm consumers. Respectively, a negative asymmetry in price transmission will benefit consumers and harm producers.

Asymmetry in the magnitude of price transmission suggests that price increases are transmitted more fully than price decreases, or vice versa depending on the circumstances in the market (*Figure 12*). Therefore, magnitude-related asymmetry refers to the intensity of the impact the changes in the price will have and is normally linked to permanent transfer and effects on markets that strongly depend on further changes in prices and volumes (Frey and Manera, 2007). Speed-related asymmetry occurs when an increase in the price is passed-through less rapidly than a price decrease, or vice versa (*Figure 13*). This is often associated with temporary relocation of benefits and effects on the market that depend on changes in price, volumes but also time lag (Aragrande and Canali, 2017).

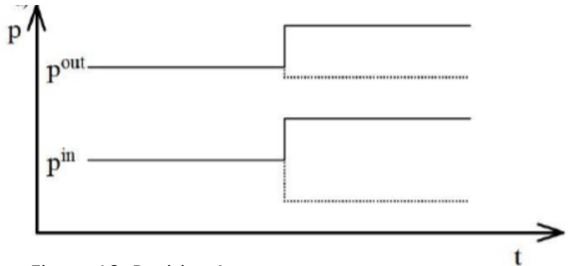


Figure 10. Positive Asymmetry

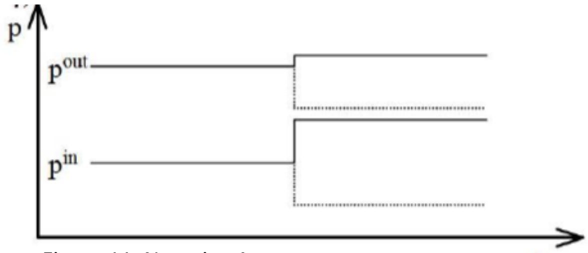


Figure 11. Negative Asymmetry

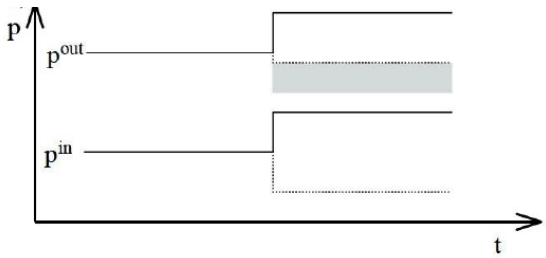


Figure 12. Magnitude of Asymmetry

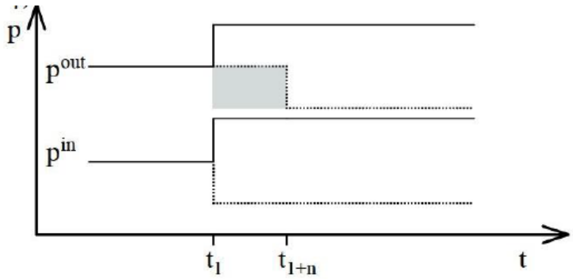


Figure 13. Speed of Asymmetry

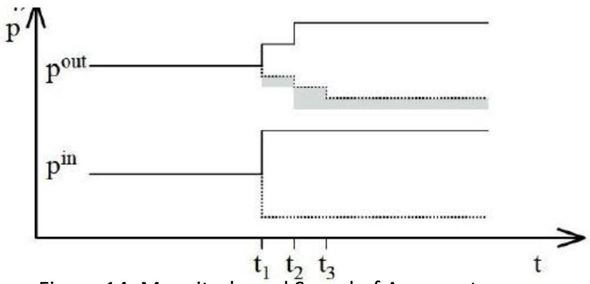


Figure 14. Magnitude and Speed of Asymmetry

Source: Meyer and von Cramon-Taubadel (2004)

In addition, asymmetries in the price transmission process can be classified as spatial asymmetries when they occur between geographically separated markets or vertical if they occur within the supply chain (Meyer and von Cramon-Taubadel, 2004); this is otherwise known as the direction of asymmetry.

Regardless of the type, the presence of asymmetries in the price transmission process may indicate where market power lies among the market players; thus, pointing policymakers in the right direction when they attempt to address this (Peltzman, 2000).

2.1.5 Causes of Asymmetry

The causes of asymmetries in price transmission have been widely examined by researchers. This examination is a very important metric that can point to gaps in economic theory and help in policy decision making. Asymmetry is usually a sign of market failure; therefore, it attracts high interest from researchers that investigate market performance (von Cramon-Taubadel and Meyer, 2001). Past literature has identified the following causes of asymmetries.

2.1.5.1 Market Power

Market power is almost always presented as a cause of asymmetry in studies that investigate price relationships (Abdulai, 2000). The presence of market power in an industry is found when there is a small number of competitors and non-competitive behavior. Therefore, theory suggests that having a small number of competing firms in an industry will increase asymmetries in price transmission (Bakucs *et al.*, 2013). This is also supported by Blinder *et al.* (1998) who indicated that some corporations may obtain market power due to lack of competitors in the same region, such as in the case of a monopoly. This can lead to incomplete information and potentially uncertainty for the consumers since retailers can reduce prices at a slower rate than increase prices.

The exercise of market power by firms leads to a series of events that aim to increase their profitability. Based on their position in the market and overall capabilities, firms either act as price-makers or price-takers. Price-makers control and adjust prices in response to market triggers, to reduce the risk of a negative impact on them (Landazuri-Tveteraas *et al.*, 2017). For example, an increase in input price is highly likely to be passed over to consumers, while a decrease in input price may be caught up in the mark-ups and exploited by the sector. In terms of price movements, those that pose a threat for the firm’s margins may be transmitted more rapidly by downstream players, in contrast to price movements that may favor the firm’s margins, which lead to asymmetries in the price transmission (Bakucs *et al.*, 2013).

Although most studies suggest that market power causes asymmetries, evidence also supports that market power is not necessarily associated with asymmetries (Serra and Goodwin, 2003). McCorriston *et al.* (2001) demonstrated that increasing returns to scale can counterbalance the impact of market power on price transmission. Specifically, increasing returns to scale at producer level strengthen the producers' ability to negotiate better prices, thus weakening the influence of market power.

2.1.5.2 Market Structure

An oligopolistic market is characterised by high market concentration, as a small number of firms own a large proportion of the total market (TekgüÇ, 2013). According to general economic theory, this would mean that both a small number of firms and high market concentration in a market would increase asymmetries. However, Peltzman (2000) reached conflicting findings and concluded that where a low number of competitive firms increase the presence of asymmetries in the price transmission process, high market concentration reduces them. Similarly, Bettendorf and Verboven (2000) and Acosta and Valdés (2014), agreed with this point and explained that high concentration ratios are not fully associated with asymmetries.

Collusive behaviour can also be present in oligopolistic markets, where firms conspire with competitors secretly in order to gain a market advantage that will disrupt healthy competition (Bolotova *et al.*, 2008). For instance, a decrease in the central market prices will be transmitted at a slower pace to local market prices so that increased margins can be exploited, compared to a price increase which would be transmitted at a faster pace so that the central market could benefit from increased profits (Panagiotou, 2018).

2.1.5.3 Incomplete Information

The sharing of information is the main means of communication for economic transactions between countries (Hirshleifer *et al.*, 2005) and price information is key for the functionality of the markets when shared between consumers and producers and geographically separated markets. Other forms of information that are shared within a supply chain and/or between markets include production methods, consumer requirements and product characteristics (Aramyan and Kuiper, 2009). In the context of international trade, lack of information or incomplete information can cause asymmetries in price relationships when changes in the local market are not communicated with peripheral markets (Grigoriadis *et al.*, 2016; Meyer and von Cramon-Taubadel, 2004). For example, when there is a decrease in producer prices, the export agents may retain this decrease as profit if other agents are unaware of it. Perfect competition requires all agents to share complete price information; thus, incomplete information leads to profiting opportunities for some agents and in turn to price transmission asymmetry (Aramyan and Kuiper, 2009).

2.1.5.4 Product Homogeneity

The homogeneity of products between markets contributes to the smooth transmission of prices (Conforti, 2004; Emmanouilides and Fousekis, 2012). In the same way, the domestic version of a commodity may not be a complete substitute for its foreign counterpart, which will cause price transmission from world to domestic prices to be incomplete. Apart from product differentiation (Ghoshray, 2009), differences in consumer preferences and habits between countries lead to asymmetries, both in the short and long term (Sanjuan and Gil, 2001).

2.1.5.5 Consumer Preferences and Search Costs

Consumer preferences are determined by multiple factors, such as the product itself (product characteristics including quality, variety, and price), location and convenience (Aramyan and Kuiper, 2009).

Consumer preferences can affect the rate of production of a product and consequently its price (Loy *et al.*, 2019). For example, in the last decade consumers have turned to healthier lifestyles such as preference for extra virgin olive oil due to the health benefits it offers over refined olive oil. An increase in demand for extra virgin olive oil results in a corresponding increase in supply to meet the demand, causing a rise in its price at retail shops compared to refined olive oil. The asymmetry in this case will be linked to the speed of the price transmission. Retailers will transmit this price increase much slower to farmers to benefit from higher margins, whereas a price decrease that may be linked to a potential decrease in the demand for extra virgin olive oil will be transmitted much quicker, so that retailers can reduce the impact to their margins. On a spatial level, national preferences can also lead to asymmetric price transmission (Emmanouilides and Fousekis, 2014a). Grigoriadis *et al.* (2016) stated that consumers in North and Central Europe prefer heavier animals compared to Southern Europe where the consumer preferences are for lighter animals, and this difference may result in asymmetries. Therefore, in the context of olive oil, consumers in France prefer extra virgin olive oil compared to the United Kingdom where consumer demand for standard quality olive oil dominates. In this case, a negative price shock in one of the two olive oil types may be transmitted slower to the market with the higher demand for that olive oil type compared to the other market.

Consumer preferences are also determined by the search costs associated with a potential purchase. Consumers’ search costs refer to the energy, time, and money spent in browsing products before the potential purchase of a particular product (Chowdhury, 2004). They depend on the structure of the supply chain, which means that consumers will decide to search in alternative retailers only when prices rise over a certain threshold (Antonioli *et al.*, 2018). Search costs also consider the opportunity cost, which is the foregone benefit that consumers would gain if they were to purchase another product in the place of the one they finally decided to purchase.

In addition, asymmetry in price transmission may result from the high power that local firms enjoy in an area where there are limited options for consumers (Vavra and Goodwin, 2005). As convenience is one of the most important factors for consumers when making a purchase, they may continue to pay more for a product that they could obtain at a cheaper price if they were to buy it from another retailer based in another area. Therefore, local firms tend to respond to an increase in the prices in the central market by raising their prices immediately but lowering them at a much slower pace. This gives them the opportunity to benefit from expanding their margins in the short run as consumers may be unable to obtain complete information (Abdulai, 2000).

2.1.5.6 Food Scares and Publicity

In addition to consumer preferences, consumer perception of food safety is equally important since it also impacts price transmission. There have been numerous food scares in history; however, food safety has only become a considerable concern for the political world, the world of science, and society, since the mid-1970s (Cooter and Fulton, 2001). Several food scares made it to headlines over the past decades, which attracted the attention of consumers and the media. For example, Knowles *et al.* (2007) noted that in 1988 there were incidents of food poisoning recorded in the UK that were linked to egg and cheese consumption since they were found to be infected with Salmonella. After this food scare attracted increased publicity, the consumer demand for these products recorded a substantial decrease. Another well-known example is Bovine Spongiform Encephalopathy (BSE), more widely known as ‘Mad Cow Disease’ (MCD). This disease not only impacted the consumer demand for beef, but it also led to 4.4 million cattle in the UK being killed as a precaution. In general, food scares can cause asymmetries in price transmission indirectly by affecting consumer preferences and consequently consumer demand, alongside impacting production and, therefore, prices (Tremma and Semos, 2017). In fact, the Food Publicity Index (FPI) was developed by researchers to evaluate price changes in relation to publicity. In this regard, Hassouneh *et al.* (2010) showed that after the BSE outbreak in Spain, although prices along the beef meat supply chain decreased, the extent of price adjustment varied between producer and retailer. Similarly, Aramyan and Kuiper (2009) confirmed that the decrease in wholesale prices was less than the decrease observed at the retail level. Overall, such incidents have impacted the demand and supply of the products related to these food scares and, in conjunction with policy measures taken, contribute substantially to the price transmission process, as confirmed by Serra *et al.* (2006b).

2.1.5.7 Product perishability and storage

Evidence in existing literature indicates that price transmission processes may be affected by product attributes, such as perishability and storage ability (Santeramo and von Cramon-Taubadel, 2016; Hillen, 2021). Product perishability is a factor that concerns economic agents, especially the ones trading food products that have a short product lifetime (Commission of the European Communities, 2009). Asymmetries may arise in price transmission as firms may keep prices of perishable products low to avoid the risk of having deteriorated product surpluses that they will then be unable to sell (Ahn and Lee, 2015). Moreover, producers want to sell their products quickly; thus, they are not able to influence price formation through market power. On the contrary, products that can be stored allow producers to exercise market power and, therefore, may influence the price transmission process (Chaudhry and Miranda, 2020).

2.1.5.8 Government Intervention

A higher degree of government intervention is noticed in agricultural markets compared to non-agricultural markets (Tvrdoň, 1992), indicating higher degree of market inefficiency. However, some markets, such as that of olive oil, are characterised by a relatively lower degree of policy intervention compared to other agricultural commodities (Tvrdoň, 1992) like milk and beef. Government intervention is considered to be one of the most common causes of asymmetries in price behaviors as it creates instability for stakeholders, which may be temporary or more permanent (Kinnucan and Forker, 1987). More specifically, a high degree of policy intervention is expected to lead to asymmetries, whereas according to Zanias (1993), a low degree of intervention in markets can enhance smooth price transmission (Emmanouilides *et al.*, 2014). Similarly, in the context of European markets, Gotz *et al.* (2012) suggested that a limited amount of policy intervention is expected to strengthen the complete transmission of prices. The aim of policy intervention is to address inefficiencies in the markets and can take different forms such as changes in the Common Agricultural Policy (CAP), subsidies, regulation, taxation, tariffs and import quotas (Honma, 2019). In particular, government intervention in the form of trade policies directly impacts spatial price transmission, whereas domestic policies have a higher impact on vertical and horizontal price transmission process (Bobokhonov *et al.*, 2017). For example, import quotas or trade tariffs can cause lags in price transmission and consequently lead to asymmetries. Furthermore, strategies to strengthen trade between international markets are implemented to integrate markets. For instance, the North American Free Trade Agreement (NAFTA) strengthened the integration between the agricultural markets of the USA, Canada, and Mexico (Zanisher *et al.*, 2015).

Another example of policy intervention that relates to agricultural commodity markets are measures taken for disease control. This may also include measures that relate to inventory management practices (Meyer and von Cramon - Taubadel, 2004).

2.1.5.9 Stock Practices and Inventory Management

Incomplete spatial price transmission can be augmented by inventory practices both in the short and the long run (Blinder, 1982; Meyer and Von Cramon-Taubadel, 2004; Rapsomanikis *et al.*, 2003; Emmanouilides and Fousekis, 2012). Firms adjust their stock practices based on commodity price signals which trigger stock accumulation or stock release (Blinder, 1982; Peltzman, 2000). Inventory holders monitor the central market conditions, and, in response, they manage their stock accordingly to prepare them for either benefit from increased profit or to withstand a possible hit (Vavra and Goodwin, 2005). If a price decrease in the central market is anticipated, firms will manage their stock levels to ensure that they will last them for a specific period of time so that they will not be forced to restock with the new higher prices and absorb an increased cost. Their aim will be to wait until prices drop to reduce purchasing costs. Comparably, if prices are expected to increase in the central market, firms may purchase larger quantities of product at the existing price before it rises.

2.1.5.10 Trade-related causes

As stated in 3.2, trade is a prerequisite for the presence of price transmission; therefore, any changes in the form, speed and direction of trade can also affect price transmission (Verreth *et al.*, 2015). Goetz *et al.* (2008) confirmed that free trade strengthens the price transmission process; therefore, any obstacles in trade can lead to asymmetries. Also, Goetz *et al.* (2008) studied price transmission in fruits and vegetables and concluded that when these products are traded internationally, this may result in abuse of market power since there is no full transparency on how producer prices are set. Moreover, Goodwin and Piggott (2001) argue that asymmetric price transmission is observed in those cases where trade between two countries is unilateral. This means that the trade flow is constantly one-way, for example when a country is always the net exporter and another country always the net importer (Emmanouilides and Fousekis, 2012). Moreover, Grigoriadis *et al.* (2016) added that physical proximity and intensity of trade flow play an important role in the price transmission process. For example, countries which are geographically closer may share price shocks more quickly than those which are further apart.

2.1.5.11 Transport and Transaction Costs

Transport and transaction costs also contribute to price transmission asymmetry. Transport costs refer to the costs associated with the movement of agricultural commodities from one agent to the other or between markets. Transaction costs are categorised as information costs, monitoring and enforcement costs, and negotiation costs (Rapsomanikis *et al.*, 2003). Higher transport and transaction costs are common in markets with poor transportation systems and poor infrastructure that lead to delays (Conforti, 2004). As a consequence, price differences between markets are extended, causing price asymmetries. This is because the prices of the components that make up transaction costs are determined locally and there is an inability to collect data (Ghoshray, 2009).

2.1.5.12 Exchange rates

Exchange rates are identified as a cause of asymmetries in studies that analyse spatial price transmission. According to Knetter (1993) and Conforti (2004), adopting a common currency between markets and agents enables smooth price transmission. For instance, price transmission between EU countries that have adopted the Euro as their currency is expected to be more fully complete. On the contrary, price transmission between the nine EU member states that have not adopted a common currency is expected to be characterised by asymmetries. It is an inevitable element in cross-border transactions and any changes in exchange rates directly impact on the cost of commodities and, thereafter, the trading prices. The impact and speed of responsiveness by firms to these changes on the output prices has been widely examined by researchers to determine which characteristics relate to different enterprise behaviors.

2.1.5.13 Other economic conditions

Economies differ among countries and various economic market conditions may also impact the price transmission mechanism. For instance, real per capita income, or differences in taxation and employment, are likely to lead to differences in price transmission between markets (Emmanouilides *et al.*, 2014). Moreover, according to Chen *et al.* (2008), inflation can cause asymmetries to some extent, since it involves a degree of adjustment required in response to changes in input prices.

2.1.5.14 Production-related causes

Production-related causes of asymmetry are a frequent phenomenon in the case of agricultural commodity markets. Compared to non-agricultural commodities, where production can be controlled more easily, the production for agricultural commodities is highly dependent on factors that are, in many cases, uncontrollable or hard to fight. Examples of these factors include adverse weather conditions, crop diseases or zoonoses. Under symmetric price transmission, a change in production would cause an equal change in the consumption of a commodity. However, sometimes changes in the price at production level are not transmitted at the same rate as price changes at the processing or retail level, suggesting the presence of asymmetric price transmission (Bor *et al.*, 2013). In addition, Aramyan and Kuiper (2009) suggested that asymmetric price transmission may be linked to the product’s special characteristics, such as bulkiness. This may create an additional requirement in the production process of this type of product, including an adjusted type of supply chain. For instance, in the case of olive oil, this may be noticed in Italy’s olive oil supply chain, when in several cases the production process involves converting olive oil from one form to another, such as from bulk to retail. Italy is known to import olive oil in bulk quantities from different countries, such as Greece and Spain, bottle and rebrand, and finally reach the retail stage as Italian olive oil

(Mylonas, 2015). Therefore, bulkiness in this case can cause asymmetries in the price transmission, since this creates a longer supply chain (Aramyan and Kuiper, 2009).

2.2 Empirical work and previous research on price transmission

This chapter will include a review of past literature and empirical work that has focused on price transmission in agricultural commodity markets. The first part will be a literature review on Horizontal Price Transmission and studies are categorised based on the empirical methodology they employed. This will be followed by a literature review of studies that investigated Vertical Price Transmission arranged as per the type of agricultural commodity they studied. Then, the chapter will focus on studies that have analysed Price Transmission in edible oil markets and conclude in studies that specifically investigated olive oil markets. Finally, a systematic mapping approach will be taken to map studies that have been undertaken on price transmission in edible oil markets with a focus on olive oil, to establish and highlight the research gap.

2.2.1 Horizontal Price Transmission: Literature Review

Horizontal price transmission has been extensively studied by several authors over time, with different empirical methods. It is determined that the most popular and widely used methods are the cointegration tests such as the ones proposed by Johansen and Engle-Granger along with Error correction models (VECM, ECM, VAR), threshold autoregressive (TAR) and momentum threshold autoregressive (MTAR) models. Moreover, Asymmetric Error Correction models and Threshold Vector Error Correction models, Markov-Switching regime error correction models and more recently copulas and wavelets have been employed to examine the price transmission mechanism. In addition, researchers detect the central market which is the market that leads price formation and shocks originate and activate responses to other markets (Goodwin *et al.*, 1999), by setting the characteristics of the leader-market (Serra et. al 2006; Gervais, 2011) or by applying causality and exogeneity tests (Fousekis and Trachanas 2016; Abdulai, 2002). In terms of causality tests, the most widely used by researchers, is the linear technique of Granger Causality test. Furthermore, the non-parametric test of Hiemstra and Jones (1994) which accounts for non-linearities and considers series dependence, and the non-linear causality test of Diks and Panchenko (2006) have been widely applied in economics related research and recently in price behaviour studies (Rahimi *et al.*, 2016; Nie *et al.*, 2017; De Vita and Trachanas, 2016; Shahbaz *et al.,* 2017).

2.2.1.1 Studies employing the Cointegration test of Engle-Granger and Johansen

The application of cointegration test enables researchers to examine the degree of market integration and price transmission between the markets. Based on literature, the most common cointegration techniques applied are those of Engle-Granger and Johansen.

Both methods enable the determination of a long-run relation; however, the difference between them lies in the fact that Engle Granger is a bivariate technique where the researcher sets the independent and dependent variable, whereas Johansen (1988) is a multivariate test, which is considered efficient in investigating long-run relations among stationary series allowing for the testing of multiple cointegrating vectors.

In this respect, Asche *et al.* (2007) analysed the price relationship between the UK, Norway, and France for salmon. They utilised the Johansen Cointegration Test as a multivariate approach and VECM to determine the number of cointegration vectors and employed monthly farm, retail and export price data. Evidence showed high degree of price transmission between the UK and France, and that the LOP holds at producer and export prices between the UK and Norway. Also, there appears to be an absence of transaction between the UK and Norway between the producer levels, therefore price changes are transmitted downstream to the levels where the two producers compete. This may be a result of past trade frictions between the two countries. Noteworthy is the fact that, although the UK is not the biggest producer, UK appears to be the price leader and Norway the price follower for producer prices. This may be since anti-dumping complaints have been filed by Scottish producers against Norwegian salmon in the UK market, which caused short term trade restrictions to be implemented by the European Commission, or due to feeding restrictions/feed quotas that were introduced by the Norwegian government following pressure from the European Commission. Therefore, the UK had more freedom in the short term to take control of the market, creating a situation where Norway is responding to triggers in the UK market; thus, being the price follower.

Moreover, the Johansen cointegration test was applied by Menezes and Dionísio (2008) on monthly vessel prices in Norway, import prices of wet salted cod from Norway and retail prices of salted cod in Portugal, to determine the behaviour of price transmission along the cod value chain between Norway and Portugal. The findings indicated a long run relation between all the examined pairs, whereas the threshold cointegration tests showed no evidence of asymmetric price transmission. Some differences in the margin sizes have been noticed, but these were linked back to potential uncertainty in the supply of the product.

Causality has also been a topic of interest in studies for market integration and price transmission, where authors attempt to determine which is the causal market for a particular commodity, thus, the market causing price changes in other linked markets. In these lines, Habte (2017) assessed market integration, price transmission and price causality between five papaya markets in Ethiopia. Utilising monthly retail prices, several empirical tests have been performed to determine the price relationships between the five regions. Cointegration relationships were found and overall, the speed of price transmission was found to be slow which can be explained by poor infrastructure, high transportation costs, inaccurate price information and lack of government policies. The results of the Granger Causality tests show that Abraminch is the causal market in the short run.

The EU dairy markets have been investigated by Bakucs *et al.* (2015) who examined the spatial price dependence, using monthly producer prices of raw cow milk. The empirical strategy for this analysis included VAR models, unit root tests and Engle and Granger cointegration tests. In addition, this study considered LOP for cointegrating prices pairs. The LOP in its weak form was found to hold in almost half of the cointegrating pairs. However, the LOP test was applied on non-cointegrating pairs as well, since it was assumed that price information does not require physical trade to flow. This assumption was verified through evidence, which showed that error correction between price margins takes place as long as markets consider other markets' prices, and regardless of whether trade is established between markets or not. Overall, as LOP was only found to hold in a very small percentage of all possible pairs, the majority of the dairy markets in the EU appear to be inefficient.

Looking outside the EU, Newton (2016) tested price transmission across the main international dairy markets (EU, Oceania, US) using VAR and VECM. Results supported a unidirectional relation with price shocks in the EU and Oceania cheddar, butter, and skimmed milk markets to be transmitted to the US markets. Moreover, EU and Oceania dairy markets were highly integrated which is in line with the studies of Fousekis *et al.* (2016a); Fousekis and Grigoriadis (2016a).

In the same lines, Zhang *et al.* (2017a) assessed price transmission in the major whole milk powder markets (Oceania, EU, US). Results provided evidence of integration among the three markets to an extent; OC and EU were found to be well integrated both in the short and long run. However, price shocks from US were not transmitted to any other market; indicating that the US does not lead price formation in the international powder markets. This is in line with Newton (2016), who suggested a unidirectional relationship for US dry milk powder since only price changes in Oceania were spread to the US.

In the context of meat markets, Umar *et al.* (2013) examined the broiler chicken sector in 11 regional markets in Malaysia using wholesale average monthly prices from January 2000 to December 2011. ARDL was employed to estimate price linkages and lags in the long run and ECM test was carried out to measure short run and long-run elasticity. Finally, the Granger Causality test determined the direction of the price relationships in the short run. The results showed a long-run relationship between the regional markets, a bidirectional causal relationship between the terminal market and East-Coast market, and unidirectional causal relationships from the South-region and the North-region to the central wholesale market.

Sanjuán and Gil (2001) utilised wholesale weekly prices from the European Commission database for pork and lamb, in order to evaluate the efficiency of seven EU markets. Data spanned from 1988 to 1995 and ADF and KPSS unit root tests were employed as well as VAR and Johansen (1988) multivariate cointegration tests to analyse long-run linkages. In addition, Granger causality tests were performed to find out the leader-follower relationships and Forecast Error Variance was utilised to analyse short run movements. The EU pork and lamb markets were found to be integrated both in the long and short run. Moreover, price transmission is slower and less complete in the lamb market, which may be explained by heterogeneity in lamb production systems compared to pork production systems.

Pork, in particular, is one of the most-studied agricultural commodities, not only in terms of market performance between countries, but also in comparison with substitute products and other agricultural commodities within the same country. Carraro and Stefani (2011) attempted to study the mechanisms of horizontal and vertical price transmission in lamb, pork and pasta markets in Italy, accounting for the general price instability of the previous period, to examine for possible asymmetries. Applying the cointegration method of Engle-Granger in prices pairs and incorporating price adjustments, the presence of long-run equilibrium between wholesale-retailer prices in lamb and semolina was confirmed. However, considering price adjustments, a similar relationship was denoted between producer-wholesaler prices. A significant finding of this study was that it uncovered a tendency towards asymmetric price transmission in pork and pasta markets, while a change in the price transmission mechanism was denoted in both cases during the rise in prices in 2007-2008.

Finally, Esposti and Listorti (2013) assessed the impact of price bubbles on agricultural price transmission with market focus on durum wheat and corn in the EU and North America. Cereal weekly spot prices were employed spanning from May 2006 to December 2010. Results showed that price bubbles have minimal impact on price transmission; however, this is limited even more through trade-policy measures.

2.2.1.2 Studies employing the Threshold autoregressive (TAR) and Momentum autoregressive (MTAR) models

Among the most popular cointegration techniques that researchers used to measure price comovements are the Threshold autoregressive (TAR) and Momentum autoregressive models (MTAR). These models allow the detection of thresholds caused by transaction costs (Goodwin and Piggot, 2001) and in contrast to Johansen and Engle-Granger cointegration which assume linear price adjustments, these methods enable researchers to test for non-linearities caused by the threshold effects. The threshold has an effect when a price shock, greater than its value, causes different responses compared to price shock below this threshold; thus, indicating asymmetry in the price adjustment process. Based on Listorti and Esposti (2012), through TAR and MTAR models researchers can provide information regarding price dynamics and constitutes a measure of spatial arbitrage violation (Fackler and Goodwin, 2001). However, a limitation of these methods is the constant transaction costs assumed (Abdulai, 2007), which encouraged the development of techniques that include regimes in the process.

In this respect, Gonzales *et al.* (2002) studied asymmetric price transmission in relation to different characteristics of product supply, focusing on farmed versus wild-caught fish. The dataset included monthly price series for whole fresh wild cod and farmed salmon from February 1988 to December 1999 for the French and Norwegian markets. Cointegration analysis was performed, and asymmetries were explored through TAR and MTAR models developed by Enders and Granger (1998), along with asymmetric error correction model. In both wild cod and farmed salmon markets, prices were shown to be cointegrated in the long run in both upstream and downstream cases. Price transmission appears to be symmetric in the case of cod, even though a symmetric adjustment was stronger in the case of salmon. The results provided no evidence of asymmetric price transmission between the two markets, despite product perishability. This contradicts previous literature which suggested that farming would show less asymmetries due to higher security of supply through production in a monitored environment.

Similarly, a recent study by Gizaw *et al.* (2021), examined the presence of asymmetric price transmission in the value chain of whole fresh salmon (unprocessed) and smoked salmon (processed) in Norway. The study assessed the price behaviours from Norway as the export market to retailers in France and Spain. The data employed corresponded to retail prices in France and Spain and Norwegian export prices. The empirical analysis consisted of ADF stationarity test and Enders and Siklos (2001) Threshold cointegration alongside Threshold Asymmetric ECM, to investigate whether there are asymmetries between the price adjustments in the upstream and downstream markets. The results showed that prices in the upstream and downstream markets were cointegrated in the case of fresh salmon in France and Spain. However, this was not the case for smoked salmon. Asymmetries were found between upstream and downstream prices in both markets for fresh salmon due to adjustment costs. There is limited evidence of price transmission in the value chain of smoked salmon, which may be due to delays between importing raw fish and processing as different processing companies have different production strategies and capabilities. This market is also characterised by high use of contracts where prices remain fixed for processed products, which results in delays in price transmission and outdated price information. Overall, it can be supported that price transmission is slower and less complete in more processed products compared to less processed products.

Antonioli *et al.* (2018) analysed price transmission between conventional and organic fluid milk markets in Italy. The original hypothesis suggested that there would be asymmetries in price movements between quality-differentiated products. However, the study's results contradicted this assumption. The dataset consisted of monthly processor prices and consumer prices for both products covering the period from 2001 to 2015. Initially, PP and KPSS unit root tests were applied, followed by the Generalised Least Square-Augmented Dickey-Fuller (GLS-ADF) and Johansen Cointegration to test the long-run relationship. TAR, MTAR and VECM were also performed to capture possible anomalies in the movement of prices over time. In the long run, the organic milk market appears to be more responsive than the one of conventional milk, since organic milk prices comove for the whole examined period, whereas conventional milk prices comove only from 2010 onwards. This is attributed to the fact that before 2010, prices were determined by the retailers' supply and demand and not their prices, meaning that any unforeseen changes from either side of the chain would not be transmitted upward or downward along the supply chain. In the short run, the supply of organic milk is relatively inelastic compared to that of the conventional milk, since an increase in consumer price for organic milk causes a larger increase on the processor price. This may be since there are fewer producers of organic milk than conventional milk, therefore organic milk producers have higher bargaining power and higher control on the supply, which enhances their response capability to adverse market conditions. The results of Antonioli *et al.* (2018) are consistent with Serra and Goodwin (2003) regarding dairy market in Spain, and Bakucs *et al.* (2012) for Hungary.

Milk has been the focus of another study that was conducted by Jaramillo-Villanueva and Palacios-Orozco (2019), in relation to spatial and vertical price transmission. The aim of this study was to assess the efficiency of the Mexican and International dairy markets, by investigating the degree of price transmission between farm prices in Mexico and International prices of milk, as well as between Mexican farm and retail milk prices. Using monthly milk spot prices from January 1990 to December 2016, the Engle-Granger two-step cointegration analysis was conducted alongside Johansen cointegration, to test for the long-run relationship. Moreover, asymmetries have been considered by performing the asymmetric VECM test. A long-run relationship was found, and Mexican milks prices appeared to be consistently influenced by price movements in the international milk prices. Asymmetries have been detected in spatial relationships where a price decrease in the international market is transmitted quicker to farmers in Mexico than a price increase. In terms of the vertical aspect in the Mexican milk market, retailers' prices are highly affected by producers' prices, where a decrease in producers' prices is responded to by a faster speed of adjustment.

Acosta *et al.* (2014) examined the price relation of domestic and global milk markets, using monthly producer prices for Panama and FOB prices for Oceania regarding 2000-2011. Results indicated that prices are transmitted from global to domestic markets with a low magnitude due to import tariffs. Moreover, the presence of asymmetries is implied through the AECM; supporting that price increases are transmitted with a greater speed from global to domestic markets than decreases.

Comparably, Liu (2011) investigated horizontal price transmission between Finnish pork and beef markets and major EU players such as Germany and Denmark. Weekly price data for both commodities in Finland, Germany and Denmark were utilised, spanning from 1995 to 2009. In the long run, a symmetric cointegration relationship was found between Finnish and German pork markets and between Finnish and Danish pork markets. These results are consistent with Emmanouilides *et al.* (2013). However, asymmetries were spotted in all examined price pairs in the beef market; thus, concluding that the Finnish pork market is more efficient than the beef market.

The Turkish wheat market has been studied by Weitzel and Bayaner (2006) in terms of spatial price transmission between provinces in Turkey. Data consisted of producer average monthly prices from January 1994 to December 2003 and asymmetries were considered through an asymmetric ECM. Results showed that 58% of all possible pair combinations were cointegrated, and symmetric adjustment processes were found for the majority of the pairs.

Varela and Taniguchi (2014) tested for asymmetric price transmission in Indonesia's wheat flour market. This was pursued using asymmetric error correction model on monthly domestic (Indonesia) and international retail prices of wheat flour. Findings supported evidence of asymmetries in the price transmission between these markets in the short run and concluded that these are due to asymmetric information, high cost of adjustment and market concentration of wheat flour milling. The study highlighted the contribution of oligopoly market structure on asymmetric price transmission; thus, preventing market integration.

Furthermore, Thompson and Bohl (1999) examined international wheat price transmission in relation to Germany. Monthly domestic producer prices for Germany were employed and CIP Rotterdam price data for the international market. The price dataset spanned from June 1976 to December 1998 and was used to perform ADF unit root and Enders and Siklos (2001) MTAR cointegration test. Results revealed steady relationships in the long run between the German and International markets for wheat.

A high degree of market integration was also found in other cereal markets, such as maize. Abdulai (2000) examined price relationships between major maize markets in Ghana using monthly wholesale prices for 1980-1997. TAR, MTAR and asymmetric error correction models were employed to test for asymmetries and ARCH model to examine price volatility. The findings of this study suggested a strong long-run relationship between the markets, however asymmetries were found in the speed of price transmission, since prices in local markets responded quicker to increases in the prices in the central market than to price decreases. This was due to higher transaction costs which were linked to poor infrastructure or inventory management.

Overall, the markets of cereal appear to be well-integrated with some asymmetries found in the price transmission process. This is also consistent for the rice market, based on the study by Ghoshray (2008) who utilised monthly average export prices for the two leading rice exporters, Thailand, and Vietnam for 1997-2006. Findings indicated asymmetries for high and intermediate quality rice in Vietnam as this is a relatively new market for Vietnam that traditionally produced low quality rice.

Worako *et al.* (2008) examined the effect of market trade reforms in Ethiopian coffee markets' and global coffee markets' price relations. The dataset that was used for this study included monthly produce, national average price of coffee, and auction and FOV prices from October 1992 to September 2006. Results indicated that, in the short run liberalisation reforms improved price transmission and in the long run they have strengthened relationships between the examined markets.

2.2.1.3 Studies employing alternative Non-linear and non-parametric models

The previous examined models assume linearities and/or constant transaction costs; thus, the properties of the underlying reaction functions and the complex dynamics which characterise the agricultural commodity prices are not considered (Hamulczuk *et al.*, 2019; Fousekis, 2018). In this vein, techniques which incorporate multiple regimes, non-linearities and asymmetries in the short and long run, have been developed. These include exogeneity tests, Non-linear Autoregressive Distributed Lag (NARDL) model and non-parametric polynomial models. Moreover, Markov-switching regime models and MS-VECM models have been introduced, providing the advantage of price behaviour being regime dependent, leading to flexible model specification compared to traditional VECM (Busse *et al.*, 2010; von Cramon-Taubadel, 2017).

Similarly, Bakucs *et al.* (2019) investigated spatial price transmission in EU cow milk markets considering 20 new and old member states. Results supported a low degree of market integration, since 35% of the examined pairs were cointegrated and the Law of One Price held in its weak version for 16.5% of them. A gravity model employed through a non-parametric discrete-choice model indicated that the distance is an inhibitor of full price transmission, while the trade between old members enhanced price transmission.

In addition, Fousekis (2018) employed pairwise rank-based cointegration techniques to assess the degree of market integration in EU cow milk markets, for the period 2003-2017. Results confirmed that markets were integrated to a high extent and in most cases, prices were linked to the EU-28 average price. Moreover, Fousekis and Trachanas (2016) tested the price dependence regarding EU, USA, and Oceania skim milk powder markets, using the NARDL model. Asymmetries were revealed in the price transmission in most of the examined pairs, which were attributed to tariff/trade policies.

The EU pork market was investigated by Fousekis (2015), who examined spatial price transmission in Germany, Spain, France, Poland, and Denmark, through the use of non-parametric Local Linear regression. Results provided evidence of asymmetries in the EU pork markets, due to market power and exchange rates since not all examined countries have adopted the Euro as their currency. Serra and Gil (2006) also studied price relationships in the pork markets between EU countries through local polynomial and TAR models. The spatial analysis focused on Germany, Spain, France, and Denmark and employed weekly producer prices from 1994 to 2004. Results confirmed that EU pork markets were cointegrated and spatial price transmission was only symmetric between Spain and Germany. This could be explained by the fact that Germany and Spain are the biggest producers for pork in the EU, therefore prices comove as part of competition. In contrast, asymmetries were found between Germany, Denmark, and France. Physical distance and less intensive trade were identified as the causes of asymmetries in this study which is in line with Fousekis (2015).

2.2.1.4 Studies employing Copulas and Wavelet analysis

The most recent methods applied to measure price transmission is that of copulas and wavelets. Although copulas are traditionally used in risk management (Kole *et al.*, 2007; Goorah, 2007; Feng *et al.*, 2020) and science-based research (Anderson *et al.,* 2019), in the latest years bivariate and multivariate copulas have been employed in agricultural economics-related studies. This is due to the advantages the method offers to precisely deal with nonparametric dependencies among variables (Danaher and Smith, 2011), and enables the determination of common behaviour in random processes (Hochrainer-Stigler, *et al.*; 2018; Reboredo, 2011). Moreover, copulas provide evidence for the extent and structure of price dependencies (Emmanouilides *et al.*, 2013) and can capture both linear and nonlinear price behaviours; thus, dealing with asymmetric comovements (Mensah and Adam, 2020). In addition, wavelet technique allows the decomposition of price series into different scales and frequencies (Zhang *et al.*, 2017b; Rhif *et al.*, 2019), which enables the investigation of long and short-run price adjustments (Habimana, 2019; Berger and Gençay, 2020).

Within the agricultural market, Fousekis *et al.* (2016) examined price dependency between EU, Oceania, and US dairy markets through the contemporary empirical method of kernel-based copulas. Results supported that, prices moved together and throughout the years a proportional increase in terms of strength was identified. The price pair EU-Oceania was found to exhibit the highest levels of price dependence which was attributed to trade intensification.

In addition, using the non-parametric wavelet analysis, Fousekis and Grigoriadis (2016a) evaluated price linkages in the USA, EU and Oceania skim milk powder markets under different time horizons and frequencies. Results varied; at the high frequency levels, markets exhibited a low degree of price dependence suggesting that prices are transmitted with less intensity. Moreover, changes in the EU prices triggered changes in the USA prices. At the low frequencies, changes in EU and Oceania prices evoked responses to the USA prices. Among all the price pairs, EU-Oceania was found to be the most integrated due to the intensified trade.

Price comovement in the main international butter markets (EU-Oceania) was analysed by Fousekis and Grigoriadis (2016b) for 2001-2015. Combining copulas and wavelet analysis, the study evaluated price transmission in terms of strength and pattern under different scale levels. In the short and medium run horizons, results supported a weak price relation. In the long run though, results indicated that markets are integrated. However, there is evidence of asymmetry showing that extreme price increases are transmitted with greater intensity compared to extreme price decreases.

Price relationships in wheat markets were examined by Qui and Rude (2016) who focused on the price transmission between Ukrainian and World wheat markets. Weekly wholesale prices for wheat in Ukraine were used and FOB prices for World wheat market, from January 2005 to December 2011. Stationarity of the series was tested with ADF and KPSS unit root tests and Johansen (1988) trace test for cointegration was performed. Error correction-GJR-GARCH model was also employed along with copulas, suggesting that the domestic and world wheat markets were cointegrated with some asymmetries being present.

In addition, Emmanouilides *et al.* (2013) analysed the EU pork market and results were consistent with Sanjuán and Gil (2001) in terms of market integration and efficiency. The study employed weekly pork prices for European countries from January 2007 to September 2013, while ARMA-GARCH models and copulas were performed. Results supported that the EU pork market was highly integrated, however asymmetries were detected, which mainly relate to newer member states, geographically separated countries, and the central market of Belgium. The majority of price pairs were found to comove, and asymmetries were present at very small percentages ranging from 4.6% to 6.0%.

2.2.2 Vertical Price Transmission: Literature Review

Researchers have extensively analysed price transmission mechanism along the supply chain in several markets. In this section, a review of past literature that focused on vertical price transmission will be presented. Studies have been organised in commodity categories.

2.2.2.1 Studies investigating vertical price transmission in meat markets

Concerning the EU meat industry, Von Cramon-Taubadel (1998) investigated the long-run relation of German wholesale and producer pork prices through asymmetric error correction models. Results confirmed the presence of asymmetries and further indicated that wholesale pork prices adjust faster to positive shocks originating from producer prices. Similarly, Abdulai (2002) used a threshold vector correction model in Swiss producer and retail pork prices and concluded that retailers adjust quicker to increases in producer prices than decreases; further indicating an asymmetric pricing behaviour on behalf of retailers.

Regarding the UK, Tiffin and Dawson (2000) tested producer and retail lamb price spread, using Gregory and Hansen cointegration test and incorporating structural breaks. Granger causality test was also applied to explore the direction of the examined relation. Findings supported a long-run relation between farm and retail prices; however, elasticities suggested an imperfect price transmission. Moreover, a unidirectional relation has been found from the retailer to producer prices. In addition, Lloyd *et al.* (2004) examined price transmission along the UK beef, pork, lamb and chicken retail-wholesale prices, and findings confirmed the presence of market power. Under this condition, the effect of substitute availability on price formation has also been highlighted, due to the oligopolistic nature of the food retail market in the UK.

Alongside, Bojnec (2002) explored price behaviour within the Slovenian pork and beef markets, during the period 1990-2000. Results from Johansen cointegration test supported a long-run relation between farm and retail prices in both meat markets. Also, the findings from structural tests through imposed restrictions suggested the presence of market power within the beef sector since a mark-up of retail price has been included on the top of a constant margin. However, vertical integration within the pork sector led to smooth price transmission across the stakeholders, despite the imposed regulation in the Slovenian meat market.

The Hungarian beef market has been examined by Bakucs and Ferto (2006). The study explored the farm-retail price transmission mechanism through the Gregory Hansen cointegration test, considering asymmetries along with structural breaks using recursive ADF test. Findings from causality test suggested that producer prices granger cause retail prices. Moreover, symmetric price transmission has been verified in the short and long run; thus, suggesting a non-competitive market and lack of market power exercised by retailers.

Moreover, Ben - Kaabia and Gil (2007) investigated the long and short-run relations between farm and retail prices in the Spanish lamb market. This was pursued using a Threshold Vector Error Correction model allowing for asymmetries and non-linearities. Results indicated a symmetric long-run relation; however, asymmetries were found in the short run, due to retail market power, product perishability and inventory management practices.

In the same vein, Goodwin and Holt (1999) and Goodwin and Harper (2000) employed threshold cointegration models to explore asymmetries in the US beef and pork supply chain actors, respectively. The studies concluded that adjustments to exogenous shocks across levels of the supply chain are nonlinear and asymmetric, whereas unidirectional causality relations have been confirmed from producer to wholesale and retail prices. Furthermore, Vavra and Goodwin (2005) examined vertical price transmission between the US farm, wholesale and retail beef, poultry, and egg prices. Findings, through a threshold vector error correction model, validated asymmetries in the price transmission mechanism. Relevant literature related to spatial and vertical price transmission in the US meat markets has been evaluated by Goodwin and Vavra (2009), who pointed that existing studies on the livestock sector did not account characteristics regarding the structure of the market and institutional information. In addition, through non-linear cointegration techniques the relation between farm-wholesale and retail prices for different kinds of meat was tested. Results indicated the presence of asymmetries and revealed that wholesale and farm prices adjusted more fully to shocks than retail prices. Vertical price transmission in the US pork sector has also been tested by Emmanoulides and Fousekis (2014b), who analysed the farm, wholesale, and retail prices spanning the period 1970-2012. Using copulas, results suggested price dependence between the farm/wholesale price pair for the period 1970-1990; however, retail prices adjusted with a greater intensity to wholesale price increases than decreases. Regarding the period 1990-2012, findings indicated a change in the price pattern and weak relations between the price pairs have been identified.

Also, Fousekis *et al.* (2016b) using a nonlinear ARDL model explored the US beef industry. Results confirmed the presence of asymmetries in terms of magnitude between producer-wholesale prices as well asymmetries in terms of speed between wholesale-retail prices. Similarly, Surathkal *et al.* (2014) examined vertical price transmission in the US beef supply chain (wholesale-retail prices), considering product quality differentiation. Asymmetries were also tested using TAR and MTAR models and results provided evidence of asymmetric price transmission in terms of magnitude. Findings supported that the pace of adjustment regarding retail prices depends on the quality of the product, since higher quality beef prices adjust slower to price increases compared to lower quality beef prices.

Regarding South Africa, Mkhabela and Nyhodo (2011) tested the price transmission process in the poultry sector. Asymmetries in the short and long run between farm and retail prices were examined, using Houck's model in conjunction to Error correction model. Results suggested symmetries in the price transmission adjustment, indicating that benefits are distributed equally to stakeholders. Strategies regarding shortening the supply chain in South Africa and to directly link small farmers to retailers have been proposed, as well as policies to bring farmers together aiming to increase their power and reduce the costs. In Thailand, Barahona *et al.* (2014) examined vertical price transmission in farm and retail pork and poultry prices. The long-run relations were examined through Engle-Granger cointegration test and asymmetries were considered using an Asymmetric error correction model. Results revealed positive asymmetries in the pork sector, due to emphasis given on domestic supply and restrictions imposed regarding product exports. In contrast, symmetric price adjustment was confirmed in the chicken market. This is because the poultry sector has adopted an export focused nature; thus, enhancing competition and leading to smooth price transmission between stakeholders.

Several studies have focused on the effect of zoonoses on the price transmission process. For example, Hassouneh *et al.* (2010) examined the impact of Bovine Spongiform Encephalopathy (BSE) on the relation of farm and retail beef prices in Spain for 1996-2005. This was pursued using a BSE-index and a switching -regime vector error correction model. Results showed that consumer prices responded less to any deviation occurred from the BSE crisis, whereas producer prices tend to fully respond to any adjustment. In addition, Hassouneh *et al.* (2012a) explored the Avian Influenza (AI) effect on the wholesale and consumer poultry prices in Egypt. The non-linear smooth transition vector error correction model was used, and an Avian influenza scare index was incorporated to represent the number of information available on news related to the zoonotic disease. Results indicated that wholesale and consumer poultry prices react to deviations from the equilibrium caused by the AI crisis; however, market power was exercised by retailers to increase the margins at the AI crisis period while wholesaler margins decreased at that time. In addition, findings supported that information provided to consumers should be available at the initial stages of the crisis as this will allow to boost consumer confidence and prevent negative economic impact caused by the zoonosis. Moreover, the effect of Avian Influenza outbreak on the producer-retailer price relation during 2002-2007 has been investigated by Çamoğlu *et al.* (2015) regarding the Turkish broiler sector. Using a three Regime-Switching Vector Error Correction Model (RSVECM), the study concluded that retail prices react more intense at the start of the outbreak period than producer prices. The slow response of producer prices is due to the market structure and the contracts signed with big companies, which prevents price variability. In addition, government support and measures taken to encourage consumer purchase and consumption explain the elimination of retail response as media publicity increases.

2.2.2.2 Studies investigating vertical price transmission in cereal markets

Several researchers have also examined the cereal markets. Kuiper *et al.* (2003) assessed the price relation between maize wholesalers and retailers in five main markets of Benin. The study investigated the role of stakeholders on price formation in the long and short run, accounting for urban and rural location distinction. Results supported the impact of retailers on price determination in urban markets, due to monopoly and lack of market alternatives provided to wholesalers. On the other hand, wholesalers were found to dominate rural markets since they are involved to arbitrage opportunities which allow them to affect the pricing.

Brummer *et al.* (2009) examined the policy-related impact on the pattern of price pass-through between wheat and flour in Ukraine for 2000-2004. During this period, Ukraine's trade balance changed from a net importer to an exporter, evoking policy interventions in the domestic flour and wheat market. Results from Markov-switching regime model in conjunction with breakpoint tests, suggested multiple regimes in the price transmission process and indicated that policy interventions increased price uncertainty.

Gedara *et al.* (2015) investigated asymmetries in the price transmission process for wholesale and retail rice sector in Sri Lanka. Findings suggested that markets are integrated; however, asymmetries have been identified through TAR and MTAR models. Specifically, retail prices are found to adjust quicker to wholesale price increases compared to decreases. Further analysis confirmed that asymmetries are present during the period that government had set a ceiling price in the retail sector, which consequently led to a reduced profit margin and in turn to price asymmetries.

2.2.2.3 Studies investigating vertical price transmission in dairy markets

Additionally, vertical price transmission across the dairy sector has attracted the attention of many researchers throughout the years. Dhar and Cotterill (2002) assessed price relations within the fluid milk market, in the context of a non-competitive environment. The study employed a structural approach to milk prices from four supermarket chains and milk processors in Boston, to examine the cost pass through rate towards a change in the farm level during 1996-1998. The findings suggested that market power applied by stakeholders, led to a higher increase in margins and retail prices compared to a competitive market.

Serra and Goodwin (2003) showed evidence of asymmetric price transmission in the Spanish dairy sector through threshold error correction models. The study confirmed the presence of asymmetries in the case of raw milk-sterilised liquid milk, due to menu or/and search costs. However, in short shelf-life commodities (pasteurised liquid milk, cream caramel), symmetries were detected in the farm-retail price transmission. This suggests that price transmission between perishable products is symmetric, which further confirms the findings of McCorriston *et al.* (2001) regarding market power being related to symmetric price adjustments. In contrast, Capps and Sherwell (2005) concluded that fluid milk retail prices in the US adjusted quicker to producer price increases than decreases.

Chavas and Mehta (2014) explored price relations between wholesalers and retailers in the US butter market. Asymmetries have been detected using a model which allows contemporaneous and lagged own and cross effects as well as time varying volatility. Results confirmed that price increases in the wholesalers are transmitted with a greater speed and magnitude to retailers compared to price decreases. Regarding price volatility, results suggested that it varies under different market conditions and time. Price volatility is higher on the wholesale than the retail level, and increases due to an increase in wholesale prices, which is in line with storage behaviour/stockholding behaviour.

Awokuse and Wang (2009) examined the price dynamics in US dairy products across producers and retailers. Highlighting the importance of threshold effects, results from MTAR and TAR models supported the existence of asymmetries regarding butter and fluid milk in the long and short run, due to imperfect competition and menu costs additionally. However, symmetry was revealed in the case of cheese.

Moreover, Weber *et al.* (2012) examined price transmission in the German cheese market using producer, wholesaler, consumer, and world market prices concerning 1997-2011. The covered period was split into sub-components accounting for the change in policy in 2004 regarding intervention prices. Seasonality tests along with cointegration techniques were applied and results confirmed stable long-run relations across all levels for 1997-2004, apart from the world market prices. However, during the period 2005-2011, long-run relations were supported among all price pairs, highlighting the integration of EU to world prices. In the short run, results suggested similar patterns. During 1997-2004, world market prices affected only wholesale prices and in 2005-2011 there was an effect in all price levels.

The milk markets of Poland and Hungary have been investigated by Bakucs *et al.* (2012), who analysed stationarity in milk retail and producer prices, through the ADF unit root tests and the long-run relationship, by performing the Johansen cointegration test. The short-run relationship has been tested through the VEC and VECM models and finally, short-run exogeneity was tested through the Boswijk and Urbain (1997) test. The markets were found to be cointegrated with asymmetries being noticed in the Polish market. Milk prices in Poland were portrayed with asymmetries in the short term and the long term, in contrast with the Hungarian milk prices where it is the processing sector that rules the supply chain, which means they have more control over how they respond to market triggers; thus, it is characterized by symmetric price transmission between farm and retail stages. Also, the Polish milk sector is overshadowed by dairy cooperatives, which disrupt the direct relationship between farm and retail, which may add to the asymmetries.

De Oliveira *et al.* (2015) tested the price comovements of milk prices on a vertical scale in Portugal – in mainland and Azores, using feed prices, farm gate milk prices and milk package prices. Regarding mainland, result confirmed a low degree of integration in the long run between producer and retail prices. However, in Azores, a high level of integration in the additional price levels was supported. Moreover, it was found that after the 2008 food crisis, feed and milk farm prices exhibited a substantial decrease and became more volatile.

In addition, Lajdova and Bielik (2015) examined price transmission between farm, processor, and retail milk prices in Slovakia. This was pursued through a Vector error correction model including a dummy variable to capture possible asymmetries, and the study concluded that their presence was due to market power and product perishability.

Kharin *et al.* (2017) assessed price transmission mechanism along the cow milk supply chain in Slovakia after the abolition of milk quotas in the EU. This was pursued using cointegration techniques and VEC model. In the long run, increases in the retail prices led to increases in the farm-processor prices providing evidence of asymmetry. On the contrary, price symmetry was present between farm and processor levels, and results indicated bidirectional relations in the short run among all examined pairs.

Also, Abdallah *et al.* (2020) investigated asymmetries in price transmission of milk and dairy products between producers and retailers in Hungary. Results from the NARLD model confirmed asymmetries both in the long and short run for all dairy products, apart from processed cheese and fruit yogurt. Positive shocks in milk prices were transmitted with higher magnitude to the prices of dairy products with longer shelf life, compared to negative. On the contrary, decreases in the milk prices were transmitted with a higher magnitude to the prices of dairy products with shorter shelf life than increases. Asymmetries were mainly attributed to market power due to the high concentration on a small number of retailers and policy interventions. Similarly, Rudinskaya and Boskova (2021) explained that asymmetric price transmission in the Czech dairy industry is related to market power which is exercised by processors due to product perishability.

2.2.2.4 Studies investigating vertical price transmission in fresh produce markets

In addition, Acharya *et al.* (2011) explored price transmission between farm-retail US fresh strawberry prices, accounting for market power. Results suggested the presence of asymmetries during harvest season and high product availability, due to market power applied by producers; however, symmetries were found in the off-peak period.

Ahn and Lee (2015) employed Autoregressive Distributed Lag model (ARDL) to investigate price transmission along the fresh fruit market in the US for the period 1998-2011. Through the estimation of dynamic multipliers, asymmetries were explored in the price pattern emphasizing on product characteristics. Specifically, product perishability was accounted by using weekly data regarding FOB and terminal points for apples, peaches and table grapes. The study concluded that price adjustments were smaller in terms of extent and quicker in terms of speed, compared to peaches and table grapes. Moreover, apple which is less perishable, exhibited lower levels of price variation and positive asymmetry was detected. On the opposite, price decreases were transmitted quicker than price increases from shipping to downstream stakeholders for grapes and peaches, due to the pressure of terminal stakeholders regarding the short product life. Overall, the study highlighted the effect of product characteristics on the price transmission mechanism since differences were according to the degree of product perishability.

Vertical price transmission in the Italian fruit and vegetable sector has been explored by Santeramo and von Cramon-Taubadel (2016). Results from Asymmetric vector error correction model showed that price transmission tends to be symmetric in the case of perishable products and asymmetries occur in less perishable fruit and vegetables. Although perishability is linked to higher costs and uncertainty, findings suggested that this can be reduced using contracts.

Static and time-varying copula statistics have been employed by Ahmed (2018) to explore producer, wholesaler, and retailer price transmission in the tomato market in Egypt. Results indicated across all stages a greater pass-through of extreme price increases than decreases. This was due to the absence of forward contracts between stakeholders, which encouraged retailers to use market power. Findings are in line with Ward (1982), Ben - Kaabia and Gil (2007) and Ahn and Lee (2015), who supported the presence of prices asymmetries in the case of perishable products.

2.2.2.5 Studies investigating vertical price transmission in other agricultural commodity markets

Regarding other sectors, Cutts and Kirsten (2006) investigated vertical price transmission in several sectors (cereal, milk, cooking oil) in South Africa through an Asymmetric error correction model. Findings presented evidence of asymmetries, which were less in the case of perishable products, and market concentration was found to be related to asymmetric price behaviour.

Lastly, a multivariate panel error correction model has been applied by Rezitis and Tsionas (2019) to examine vertical price transmission in the EU supply chain for five food categories (cereals and bread, milk, cheese and eggs, meat, oils, and fats). Results showed that processor (farm) price increases were transmitted with a greater magnitude than decreases to retailers (processors), and the degree of magnitude depended on the product category while differed across countries. Asymmetries in the price transmission process were due to imperfect competition, which in turn led to the exercise of market power, adjustment, menu, and search costs as well intervention by the public.

2.2.3 Edible Oil Markets: Literature Review

Several studies have also analysed price transmission in edible oil markets both inside and outside the EU. These studies are presented in this section, which will conclude in studies that have investigated price transmission in EU olive oil markets specifically.

2.2.3.1 Price relations in edible oil markets

On a spatial level, Nkang *et al.* (2007) conducted a study on market integration and the speed of price transmission in cocoa and palm oil markets in Nigeria. Findings from the Johansen cointegration test and VECM showed that the markets were integrated in the long run for cocoa factors. Additionally, a complete pass-through of price changes from the central market (Ikom) to Etung and Akamkpa. However, no cointegration was revealed for cocoa agents due to excessive interference of Licensed Buying Agents (LBA) operations in the state. For palm oil, complete integration was shown between the central market and Akamkpa and a complete pass-through of price changes between Ikom and Akamkpa. In addition, findings revealed that the Law of One Price holds for cocoa factors and palm oil. For these cases, very high speeds of adjustment were recorded; thus, further indicating high levels of market efficiency.

The influence of the international price of crude palm oil (CPO) on the Indonesian prices of CPO and cooking oils has been investigated by Rifin (2009). Johansen cointegration test and VAR model results showed no long-run relationship between the price series. Moreover, the Granger Causality test indicated the International CPO market to be the causal market, whereas Indonesian CPO and cooking oil prices affected each other in the short run. However, a change in the price of International CPO had an instant and stronger effect on Indonesian CPO prices than on cooking oil prices. This is because palm oil is one of Indonesia's major exporting commodities and is the primary raw material for cooking oil, thus an essential product.

To assess the degree of market integration between the Indian and international markets of several commodities, including edible oils (groundnut and mustard oil), Sekhar (2012) applied the Gonzalo-Granger (G-G) cointegration model and ADF unit root tests. Findings showed that edible oil markets were well integrated domestically and internationally since they were not subjected to inter-state or inter-regional restrictions. However, commodity markets characterised by the maximum inter-state movement restrictions like the rice market did not provide evidence of integration.

In contrast, Thomas *et al.* (2013) supported through Johansen Cointegration analysis that trade liberalisation impacted the Indian economy negatively because its exposure to edible oil imports from abroad reduced the protection of domestic producers. Consequently, findings agree with Sekhar (2012) that market integration exists in edible oil markets; however, it is supported that shocks from the international market caused increased instability in Indian edible oil prices in the long run. The demand for edible oils from India and other developing countries increased due to biofuel use. This, in turn, raised prices for edible oils in the World Market.

In addition, Sundaramourthy *et al.* (2014) explored the Indian edible oil markets using Johansen and Engle-Granger cointegration tests and Granger causality test. Results confirmed the long-run relation in the oilseeds markets, and GARCH models supported the price volatility pass-through between the markets. The study reached the same conclusion as Sekhar (2012) and Thomas *et al.* (2013) that the edible oil markets are integrated since prices move together in response to changes in demand and supply. Price instability was also transmitted from one domestic market to another, with the cause of asymmetries in the volatility transmission being the uncertainty in production.

Researchers have investigated price relations within the edible oil markets on a vertical scale. Nasurudeen and Subramanian (1995) studied the price adjustment within oils and oilseeds in India both at vertical (seed to oil) and horizontal levels (different types of oil). Through Koyck’s distributed lag model, results regarding vertical price transmission showed that changes in oilseed prices were linked to changes in the oil and cake since the former is the raw material for the latter. On the horizontal scale, a high degree of integration was revealed with industrial oil prices affecting the edible oil prices. This was related to the edible oil being used for industrial purposes after some treatment. Finally, vertical integration was shown to be quicker than horizontal.

Focusing on the groundnut Indian seed-oil market, Bathla and Srinivasulu (2011) examined vertical price relations for 1996-2007. Houck's approach and AECM indicated that seed and oil markets were integrated in the long run. Seed price increases were transmitted quicker to oil prices than decreases since seeds were the raw material for the oil. Thus, an increase in their prices was reflected more fully in oil prices as oil producers needed to ensure a higher income to cover the increased cost of raw materials. The nonlinear price behaviour was explained by stagnation in yields which caused supply shortages that led to price fluctuations. Moreover, weak infrastructure, lack of price information, collusion and cartels may be reasons for asymmetries in the price transmission process. In addition, there is a high degree of government intervention on private trade-in wholesale markets; thus, firms exercise market power to avoid reducing the prices. India's oil industry is underdeveloped, which results in high processing and marketing costs. There is also evidence of inventory holding behaviour by firms, mainly when there is an expectation of high international prices leading to stock build-up to dispense the stock and take advantage of higher profits.

Chavas and Mehta (2014) explored price relations between wholesalers and retailers in the butter market regarding the US. Asymmetries have been detected using Cholesky decomposition and a model that allowed contemporaneous lagged own and cross effects and time-varying volatility. Results confirmed that price increases in the wholesalers were transmitted to retailers with greater speed and magnitude than price decreases. Regarding price volatility, results suggested that it varied under different market conditions and times. Price volatility was higher on the wholesale than the retail level and increased due to an increase in wholesale prices, in line with storage behaviour/stockholding behaviour.

Turning into the EU market, Busse *et al.* (2010) examined the German biodiesel market through the Saikkonen-Lütkepohl cointegration test and Markov-switching-VECM. Results confirmed a strong long-run relationship between crude oil and biodiesel prices and biodiesel, rapeseed, and soy oil prices. However, biodiesel prices caused weak adjustment of crude oil prices and vegetable oil prices in the short run. The asymmetry was attributed to market structure, and price adjustments appeared to be regime dependent. This is in line with Busse and Ihle (2009), who proved that German biodiesel market prices reacted faster under free-market conditions than cases where external factors intervene, such as government interventions in the form of policy failures and taxes lead to asymmetries.

Regarding horizontal price transmission, Yu *et al.* (2006) studied the relations between weekly vegetable FOB oil prices (soybean oil, rapeseed oil, sunflower oil, palm oil) and world crude oil prices from 1999-2006. Using Johansen Cointegration analysis, exogeneity tests, impulse response functions, and directed acyclic graphs analysis, findings showed that shocks in crude oil prices did not impact the variation of edible oil prices. Price dependence was confirmed between all edible oil markets since shocks were fully and quickly transmitted. Moreover, palm oil price initiated the information flow, whereas the rapeseed market was the information receiver.

Several studies have examined price relations between edible oil future markets and agricultural commodities. Meena *et al.* (2015) examined the future and spot price relations for mustard seed and mustard oil in India from 2004-2012 using weekly prices. Johansen Cointegration and VECM results indicated that spot prices were stable in the long run. In the short run, even if there were fluctuations in the spot prices due to external factors, these were well adjusted by market forces. Spot prices were affected by mustard seed and mustard oil future prices, which showed that producers have higher efficiency in managing their price risk in the future market. The efficiency of the Indian agricultural commodity futures market was further assessed by Mohanty and Mishra (2020). Future prices for nine agricultural commodities, including edible oils were derived, for 2015-2016. Results from individual and joint variance ratio tests suggested that overall, the commodities futures market in India was inefficient.

Moreover, asymmetries were revealed due to market imperfections and a lack of competitive market conditions. A similar study was conducted by Salami and Haron (2018) regarding the pricing efficiency of Malaysia's CPO market for 2009-2016. However, TAR models confirmed a symmetric long-run relationship between CPO and CPO futures prices. Finally, Liu and Sono (2016) investigated price relationships and empirical properties of the soybean, soy meal and soy oil futures prices at China’s Dalian Commodity Exchange (DCE) for 2006-2012. Johansen and Engle and Granger (1987) cointegration tests and VECM supported a long-run relation between soybean, soy meal, and soy oil future series. However, a one-way information flow was found from soy meal and soy oil to soybean markets. Moreover, the trivariate VAR-GARCH Model results indicated bi-directional flow and volatility spillover between soy meal and soy oil markets.

Regarding volatility transmission within edible oil markets, Voituriez (2001) investigated the factors that caused price fluctuations in the world palm oil market. Similarly, Balcombe (2009) studied price transmission volatility for 19 agricultural commodity prices, focusing on palm oil and oilseeds. Tiko and Odo (2012) analysed palm oil prices by examining the stability of prices and trend analysis seasonality, cyclical, and irregular elements. Sedhil *et al.* (2014) tested price volatility in agricultural commodity futures for several commodities, including edible oils and concluded that the futures market reduced price volatility for most examined markets. This was endorsed by Malhotra and Sharma (2016), who confirmed that the futures market ensured price stability. In addition, Gevorkyan (2016) analysed price volatility in future prices for renewable resources, such as palm oil and non-renewable resources, such as gold, crude oil, and estimated that volatility was greater in the first resources category than the latter. Moreover, Syahril *et al.* (2019) pointed out that exchange rates led to price volatility in the world CPO, whereas CPO price volatility affected the Malaysian CPO exports. Finally, Dutta (2019) suggested that carbon taxation led to volatility in the prices for carbon, which in turn caused uncertainty in the rapeseed oil price index in the EU biodiesel market.

2.2.3.2 Price relations in olive oil markets

There is a very limited number of studies in literature investigating price relations in the EU olive oil markets. On a spatial level, Fousekis and Klonaris (2002) investigated price linkages in three major Mediterranean olive oil markets, namely Spain, Italy and Greece. Results from the Johansen test supported that both virgin and extra virgin olive oil markets were highly integrated; however, the LOP was rejected due to high transportation costs. In the long run, as the significant surplus market, Spain leads price formation, and Forecast Error Variance (FEV) decomposition revealed that their innovations influence price series in Greece and Italy in the short run.

Emmanouilides *et al.* (2014) assessed price dependence regarding extra virgin and lampante olive oils for the same markets and accounting for asymmetries. Using copulas, market segmentation was confirmed along with asymmetries in the price transmission process. Specifically, Spanish and Italian extra virgin olive oil prices increased together but followed different patterns when decreasing. The price pair Greece-Spain exhibited similar comovement patterns in price increases and decreases, and for the pair Italy-Greece, comovement appeared slower than the rest price pairs. In the short run, the Granger causality test indicated a unidirectional relation from Italy to Spain and Greece and Spain to Greece for both olive oils. Thus, it is suggested that Italy - the most significant importer, led price formation in the rest markets, whereas Spain as the largest producer and exporter, determined Greek prices. The low degree of spatial price comovement in the EU olive oil markets was due to high transaction costs in international trade.

Price volatility transmission has been examined in the EU major extra virgin olive oil markets (Italy, Spain, Greece) by Panagiotou (2015). Results from VECM, in conjunction with a BEKK-GARCH model, supported the presence of volatility spillovers among the dominant markets. Moreover, the price dependence of the Italian bottling industry to Greek and Spanish markets has been confirmed due to the high volume of imported extra virgin olive oil in bulk on behalf of Italy. Similarly, Gontijo *et al.* (2020) analysed price volatility in US olive oil prices using GARCH models and showed that shocks of olive oil prices exhibited low volatility signs and for short periods. Thus, making it a relatively stable agricultural commodity compared to others, turning olive oil into an attractive commodity for new product markets.

Finally, the relationship between crude oil futures prices, US dollar exchange rate and international agricultural commodities prices (such as edible oils including olive oil) has been examined by Siami-Namini and Hudson (2017). Findings from GARCH models suggested the absence of volatility spillovers from crude oil prices to international agricultural commodities prices in the short run in both directions before the food crisis period of 2006. In the long run, volatility spillovers were observed from crude oil prices and shocks in the exchange rate were transmitted to the international agricultural commodities prices for the period after the food crisis of 2006.

2.2.4 Summary of previous research on price transmission

Exploring the degree of price integration among the EU markets and along the EU supply chains has attracted the interest of many researchers in recent decades. The findings from these studies can be used by economists and policymakers to understand the functionality and efficiency of markets, while also pointing to the factors that may be causing disruptions. Thus, informing future policy-making to address any inefficiencies.

Studies differ in terms of the agricultural commodity examined, the type and frequency of data used, scope, methods, and results. Findings presented in the literature are mixed regarding national and international markets, and studies focus primarily on agricultural commodities consumed and produced mainly in Northern European countries. In addition, emphasis is given on edible oils in relation to energy markets, with studies further exploring price linkages.

Researchers have examined price transmission in meat markets (Sanjuán and Gil, 2001; Tiffin and Dawson, 2000; Bakucs and Ferti, 2006; Ben-Kaabia and Gil, 2007; Goodwin and Harper, 2000; Vavra and Goodwin, 2005; Emmanouilides and Fousekis, 2014a; 2014b; Fousekis, 2015; Barahona et al., 2014; Hassouneh et al., 2012a; Umar et al., 2013; Çamoğlu et al., 2015), fish markets (Asche et al., 2007; Menezes and Dionísio, 2008; Gonzales et al., 2002; Gizaw et al., 2021), cereal markets (Kuiper et al., 2003; Brummer et al., 2009; Gedara et al., 2015; Esposti and Listorti, 2013; Ghoshray, 2008), dairy markets (Serra and Goodwin, 2003; Chavas and Mehta, 2004; Fousekis and Trachanas, 2016; Bakucs et al., 2012; Antonioli et al., 2018; Acosta et al., 2014; Abdallah et al., 2020; Rudinskaya and Boskova, 2021), fruit and vegetable markets (Acharya et al., 2011; Ahn and Lee, 2015; Santeramo and von Cramon-Taubadel, 2016; Ahmed, 2018; Habte, 2017) and seeds markets (Worako et al., 2008). Some studies also investigated a combination of agricultural commodities or different types of price transmission in the same study (Cutts and Kirsten, 2006; Rezitis and Tsionas, 2019; Carraro and Stefani, 2011).

The edible oil markets have also attracted researchers' attention primarily because of their relationship to energy markets. Price relations in edible oil markets have been examined either through price transmission (Nkang, 2007; Thomas *et al.*, 2013; Meena *et al.*, 2015) or price volatility transmission analysis (Balcombe, 2009; Senhill *et al.*, 2014; Gevorkyan, 2016; Dutta, 2019).

High degree of market integration in international markets of various edible oils is found (Nasurudeen and Subramanian, 1995; Thomas *et al.*, 2013; Sundaramourthy *et al.*, 2014) such as groundnut oil (Bathla and Srinivasulu, 2011; Sekhar, 2012), mustard oil (Sekhar, 2012), rapeseed and soybean oils (Yu *et al.*, 2006; Busse *et al.*, 2010) and sunflower oil (Yu *et al.*, 2006). The pattern of price transmission in majority is asymmetric in edible oil markets (Busse *et al.*, 2010; Bathla and Srinivasulu, 2011) and there is evidence that asymmetries are regime dependent. However, Salami and Haron (2018) concluded to a symmetric long-run relationship between crude palm oil and crude palm oil futures prices in Malaysia.

Factors that may cause asymmetries in price transmission in edible oil markets include uncertainty in production (Bathla and Srinivasulu, 2011; Sundaramourthy *et al.*, 2014), government intervention (Busse *et al.*, 2010), weak infrastructure (Bathla and Srinivasulu, 2011), and more.

In studies investigating price linkages in edible oil markets, the long-run relationships are mainly examined using cointegration techniques. Specifically, the Johansen cointegration test is the most commonly employed test (Yu *et al.*, 2006; Nkang, 2007; Rifin, 2009; Thomas *et al.*, 2013; Sundaramourthy *et al.*, 2014; Meena *et al.*, 2015; Liu and Sono, 2016); however, other cointegration tests are also utilised, such as Gonzalo-Granger (Sekhar, 2012), Engle-Granger (Sundaramourthy *et al.*, 2014; Liu and Sono, 2016) and Saikkonen-Lütkepohl tests (Busse *et al.*, 2010).

It is deduced that the interest in edible oils is mainly to those linked to biofuels and the energy markets. However, other edible oils, although important, have not attracted as much attention. In particular, the EU is the major producer worldwide regarding olive oil with Spain, Italy, and Greece constituting 95% of world production. Furthermore, a continuous increase in olive oil global demand has been observed due to its health benefits. Despite its considerable importance, a limited number of studies has examined olive oil price behavior and in particular price dependence in the dominant EU olive oil markets. Also, the supply and demand influence prices of olive oil in the EU in the major producers (Italy, Greece, Spain). Therefore, investigating the price transmission mechanism between those countries will enable the understanding of price patterns and leadership.

Fousekis and Klonaris (2002) concluded in high degree of market integration between Spain, Italy, and Greece, however Emmanouilides *et al.* (2014) reached opposite results showing a low degree of market integration for the same markets. Both studies agree that markets are inefficient, and the Law of One Price is rejected due to asymmetries found using copulas (Emmanouilides *et al.*, 2014). Mixed results also occur in terms of price leadership whereby Fousekis and Klonaris (2002) suggested that Spain leads price formation as the most important exporter, whereas Emmanouilides *et al.* (2014) concluded that it is Italy that leads prices as the most important importer. Price volatility transmission among the same three markets has been examined by Panagiotou (2015). The findings confirmed price volatility spillovers and price dependence between the main EU olive oil markets. Other studies have also investigated price volatility transmission in olive oil markets in relation to the US (Siami-Namini and Hudson, 2007; Gontijo *et al.*, 2020) with the use of GARCH models. In addition, it should be denoted that no study has considered price relations between quality-differentiated olive oils. Overall, the differences in the results regarding price linkages in the olive oil markets may lie in using different methodologies.

Researchers examined the price transmission in edible oil markets mainly assuming linear relations (Nkang *et al.,* 2007; Rifin, 2009; Sekhar, 2012; Thomas *et al.*, 2013; Sundaramourthy *et al.*, 2014; Nasurudeen and Subramanian, 1995; Fousekis and Klonaris, 2002; Yu *et al.*, 2006; Meena *et al.*, 2015; Mohanty and Mishra, 2020; Liu and Sono, 2016). A smaller number of studies employed nonlinear techniques to test the price transmission pattern in edible oil prices (Busse *et al.*, 2010; Bathla and Srinivasulu, 2011; Chavas and Mehta, 2014; Emmanouilides *et al.*, 2014; Panagiotou, 2015; Salami and Haron 2018).

In addition, studies related to edible oil- olive oil price relations identify the direction of the causality through the linear Granger causality test (Emmanouilides *et al.*, 2014), Impulse Response Functions (Yu *et al.*, 2006) and Forecast Error Variance decomposition (Fousekis and Klonaris, 2002). Nazlioglu (2011) examined crude oil and grain prices, Vasciaveo *et al.* (2013) tested the US and Italian crude oil and grain price transmission, Soni (2014) examined the relation between agricultural future contract whereas Fiszeder and Orzeszko (2018) investigated grain and livestock causal relationships.

Overall, while several agricultural commodity markets have been examined through price transmission. Considering the importance of the olive oil sector, more studies regarding this market would be expected. However, there appears to be a gap in literature for such studies. In addition, existing studies concluded to mixed results in terms of market integration and the pattern of price transmission. Therefore, the literature review has enabled a better understanding of the theoretical concepts that shape the rationale of this study, the importance of the olive oil sector and has pointed to potential gaps in the literature to be further investigated.

2.3 Evidence of price dependence in EU edible oil markets: Systematic Map

This section explores existing literature in a systematic way to understand what other researchers have done in this field and what they found. This is done through a systematic mapping process to collect, collate and establish available evidence in literature regarding the price transmission pattern in the EU edible oil markets, focusing on the olive oil price linkages ***(OBJECTIVE ONE)***. This process will allow to confirm and further establish the gap in literature for studies investigating olive oil markets.

This section will present the methodology and steps of conducting the systematic map, the results that derived from this process using the PRISMA diagram, along with discussion of findings and conclusions.

2.3.1 Data Collection Methods

Systematic mapping is a synthesis tool that identifies, and documents available evidence that relates to a particular subject area or question of interest (McKinnon *et al.*, 2015). It has been first used in social sciences (Bates *et al.*, 2007), but it has since been more widely utilised in other fields. The outcome of a systematic map is a selection of categorised publications (Littell *et al.*, 2008) which gives an overview of existing literature, potential research gaps and enables result comparison, while identifying for patterns and differences across groups of studies (James *et al.*, 2016).

Systematic maps can prove particularly useful to researchers and policymakers since they provide an assessment of knowledge gaps (Soaita *et al.*, 2019). This is the main rationale behind the decision to employ the systematic mapping process in this study. In addition, it allows replicability and transparency of the process (Haddaway *et al.*, 2016) since each step of the process is comprehensively documented; however, it does not provide an analysis of study findings. Moreover, since the aim of a systematic map lies to answering broader questions, some studies may be missed (Soaita *et al.*, 2019). This can be addressed by expanding the list of search terms and ensuring their relevance. To eliminate research bias and ensure validity and reliability, a team of researchers is required to undertake the work.

Another method that is widely used is the systematic reviews. The two methods share many similarities, however there are differences in terms of the type of research question they aim to answer, the form and depth of literature analysis and results (Haddaway *et al.*, 2016) (*Table 1*).

Table 1. Differences between Systematic Map and Systematic Review.

Stage in 'evidence synthesis'	Systematic map	Systematic review
Objective	Describes the state of knowledge for a question or topic	Aims to answer questions with a quantitative or qualitative answer
Question formulation	Question can be open-framed or closed-framed. Topic can be broad or narrow	Question is usually closed-framed
Search strategy	No limitation on research evidence that can be included (e.g. primary and secondary research)	Evidence is limited to primary qualitative or quantitative research. For example comparative, prevalence or occurrence type studies
Article screening	Articles not obtainable at full text (where the full document is not available) or studies with limited data may be included	Article full text is usually required to extract relevant data
Data extraction	Information describing the study and its methods are extracted. Study results may not be extracted	Information describing the study and its methods and studies' qualitative and or quantitative results extracted
Critical appraisal	Critical appraisal optional	All included studies critically appraised for study internal and external validity
Synthesis	Trends in the literature, knowledge gaps and clusters identified but no 'synthesis of study results' carried out	Qualitative or quantitative synthesis of study results where possible using appropriate methodology (e.g. meta-analysis). Knowledge gaps identified
Report	Describes and catalogues available evidence relating to a topic of interest, identifying knowledge gaps and knowledge clusters. Implications for policy, practice and research made	Narrative and qualitative or quantitative synthesis study results (e.g. meta-analysis) to answer the question (where feasible). Implications for policy and practice, and identification of knowledge gaps for future research

Source: James *et al.*, 2016

This study aims to present an overview of existing literature related to price relationships in the EU edible oil markets, while identifying and highlighting the gap for studies that examine price dependence in the EU olive oil markets. The process that was undertaken followed the guidelines for conducting mapping studies and was also informed by similar studies that have carried out systematic maps or reviews on the agri-food sectors.

For example, Bakucs *et al.* (2013) investigated the effect of market structure on price transmission in the agro-food sector. They used a meta-analysis of existing studies to investigate causes of asymmetric price transmission and identified 35 relevant articles. They concluded that asymmetries are more common in markets with high government intervention and fragmented farm structure. Also, Green *et al.* (2013) undertook a systematic review with meta-regression to examine the impact of food price increases on consumption and resulted in analysing 136 relevant studies. Their findings revealed that lower-income countries tend to be more responsive to changes in global food prices. In addition, Kabbiri *et al.* (2016) examined food market integration through a systematic map which generated 65 studies. They deduced that most of the research focused more on establishing the degree of market linkages but not on the implications in the examined markets.

The objective of this systematic map was set through establishing a primary research question and secondary questions as proposed by McKinnon *et al.* (2015). The scope has been defined to guide the flow of information throughout the process and the search strategy was established. In addition, the selection criteria were determined, and the search was executed. Finally, the relevant studies were selected and were subjected to data extraction and further analysis, as proposed by Salama *et al.* (2017).

2.3.2 Objectives of the Systematic Map

In order to collect and collate the available information on price relationships in EU edible oil markets, the following primary question was formulated:

What is the evidence of price dependence in the EU edible oil markets?

This research question has the following components:

- *Population* EU edible oil markets
- *Outcome* Price dependence

Secondary questions have also been set and include the following:

- Is price transmission symmetric or asymmetric in EU edible oil markets?
- What are the main causes of asymmetries in EU edible oil markets?

2.3.3 Systematic Mapping process

2.3.3.1 Search terms and Language

A list of search terms was created for each component of the primary research question; these are *Population* “EU edible oil markets” and *Outcome* “price dependence”. The search terms for the *Population* consisted of vegetable oils that are defined as edible oils as per the European Commission and other online sources, such as FAO (European Commission, 2020a; FAO, 1994; Gunstone *et al.*, 2007). The search terms for the *Outcome* resulted from a series of actions that were undertaken to identify relevant terms to price transmission. First, articles related to price transmission were gathered to determine key authors. A total of 187 articles have been included at this stage and based on this reading and personal knowledge, search terms have been identified. Second, academic journals were searched for and checked for expressions, terminology, synonyms, and different ways in which a term was used. Third, grey literature was studied to account for unpublished work and specifically, to note terminology that may be used informally. In this stage the most representative working papers and conference papers were examined. Lastly, abbreviations were used as search terms, e.g., Law of One Price – LOP or LOOP. As a next step, a pilot test was conducted on the search terms contributing to the validity of results and the final list of terms *(Table 2)* was agreed within the research team.

Table 2. List of search terms

***Population* terms**			***Outcome* terms**
Olive	Cocoa butter	Shea butter	Price transmission
Olives	Orange oil	Soybean oil	Price relations
Edible oil	Palm oil	Stillingia oil	Price co-movement
Vegetal product	Papaya seed oil	Sunflower oil	Price comovement
Vegetal products	Peanut oil	Tall oil	Price co movement

Extra virgin olive oil	Pecan oil	Taramira oil	Price interdependence
Lampante olive oil	Pequi oil	Tea seed oil	Price dispersion
Virgin olive oil	Perilla seed oil	Thistle oil	Price volatility
Crude olive-pomace oil	Persimmon seed oil	Tigernut oil	Price regime
Olive-pomace oil	Pili nut oil	Tobacco seed oil	Price inter-relationship
Refined olive oil	Prime nut oil	Tung oil	Price interrelationship
Refined olive-pomace oil	Pistachio oil	Vernonie oil	Price interrelation
Sesame oil	Pomegranate seed oil	Walnut oil	Price pass-through
Acai oil	Poppyseed oil	Watermelon seed oil	Price pass through
Almond oil	Pracaxi oil	Wheat germ oil	Price integration
Amaranth oil	Pumpkin seed oil	Macadamia oil	Price linkages
Apple seed oil	Quinoa oil	Mafura oil	Price determination
Apricot oil	Coconut oil	Marula oil	Price spillover
Argan oil	Cohune oil	Meadowfoam seed oil	Price symmetry
Avocado oil	Coriander seed oil	Mongongo nut oil	Price asymmetry
Babassu oil	Corn oil	Mustard oil	Price shock
Beech nut oil	Cottonseed oil	Niger seed oil	Market integration
Ben oil	Dammar oil	Nutmeg butter	Law of one price
Black seed oil	Date seed oil	Okra seed oil	LOP
Blackcurrant seed oil	Grape seed oil	Ramtil oil	LOOP
Borage seed oil	Grapefruit seed oil	Rapeseed oil	Price signal
Borneo tallow nut oil	Hazelnut oil	Rice bran oil	Price pattern
Brazil nut oil	Hemp oil	Royle oil	Price convergence
Butternut squash seed oil	Kapok seed oil	Sacha inchi oil	Spillover effect
Canola oil	Kenaf seed oil	Safflower oil	Symmetric price transmission
Carob pod oil	Lallemantia oil	Sapote oil	Asymmetric price transmission
Cashew oil	Lemon oil	Seje oil	Price dependence
Cocklebur oil	Linseed oil		

2.3.3.2 Search strategy

The search was conducted on 12 databases. The database selection involved finding relevant studies to price transmission or agricultural policy or trade that conducted a systematic map to gather databases used. The main criterium for selection was that the databases cover agriculture, food, economic and social science topics. Thus, databases used for this systematic map included Scopus, Web of Science, ScienceDirect, AgEcon, Food Science Source, Agri, CABI, World Bank, CAB abstracts, ProQuest, Wiley online library and Emerald.

The search string was created and consisted of two elements: *population* terms and *outcome* terms *(as shown in Table 2).* The terms were combined with the use of Boolean connectors (OR, AND) and wildcards (*) where possible. The search string was trialled to determine any database limitations *(Table 3)* and it was adapted to accordingly to meet the syntax and other possible limitations of each database. Filters were applied where possible and these included: Date 1993-2020, Subject, Publication Type such as books and conferences.

Table 3. Database limitations

Database	Limitations
Agri	No limitations
Scopus	No language selection filter
Web of Science	No limitations
Science Direct	Did not allow more than 8 Boolean connectors on each search Wildcards no supported Only up to 6,000 results available to view or download
AgEcon	No limitations
Food Science Source	No limitations
CABI	No limitations
World Bank	No filters available Results before 2000 – Error
CAB abstracts	No limitations
ProQuest	No limitations
Wiley online	Wildcards not supported No language selection filter For the subjects - had to select each one separate - could not choose more than one, so some articles may be repeated across the subjects
Emerald	No language selection filter

The two elements were combined with AND to form the search string:

(1) *Population* terms - ("olive" OR "olives" OR "edible oil" OR "vegetal product" OR "vegetal products" OR "extra virgin olive oil" OR "lampante olive oil" OR "virgin olive oil" OR "crude olive-pomace oil" OR "olive-pomace oil" OR "refined olive oil" OR "refined olive-pomace oil" OR "sesame oil" OR "acai oil" OR "almond oil" OR "amaranth oil" OR "apple seed oil" OR "apricot oil" OR "argan oil" OR "avocado oil" OR "babassu oil" OR "beech nut oil" OR "ben oil" OR "black seed oil" OR "blackcurrant seed oil" OR "borage seed oil" OR "Borneo tallow nut oil" OR "brazil nut oil" OR "butternut squash seed oil" OR "canola oil" OR "carob pod oil" OR "cashew oil" OR "cocklebur oil" OR "cocoa butter" OR "coconut oil" OR "cohune oil" OR "coriander seed oil" OR "corn oil" OR "cottonseed oil" OR "dammar oil" OR "date seed oil" OR "grape seed oil" OR "grapefruit seed oil" OR "hazelnut oil" OR "hemp oil" OR "kapok seed oil" OR "kenaf seed oil" OR "lallemantia oil" OR "lemon oil" OR "linseed oil" OR "macadamia oil" OR "mafura oil" OR "marula oil" OR "meadowfoam seed oil" OR "mongongo nut oil" OR "mustard oil" OR "niger seed oil" OR "nutmeg butter" OR "okra seed oil" OR "orange oil" OR "palm oil" OR "papaya seed oil" OR "peanut oil" OR "pecan oil" OR "pequi oil" OR "perilla seed oil" OR "persimmon seed oil" OR "pili nut oil" OR "prime nut oil" OR "pistachio oil" OR "pomegranate seed oil" OR "poppyseed oil" OR "pracaxi oil" OR "prune kernel oil" OR "pumpkin seed oil" OR "quinoa oil" OR "ramtil oil" OR "rapeseed oil" OR "rice bran oil" OR "royle oil" OR "sacha inchi oil" OR "safflower oil" OR "sapote oil" OR "seje oil" OR "shea butter" OR "soybean oil" OR "stillingia oil" OR "sunflower

oil" OR "tall oil" OR "taramira oil" OR "tea seed oil" OR "thistle oil" OR "tigernut oil" OR "tobacco seed oil" OR "tung oil" OR "vernonie oil" OR "walnut oil" OR "watermelon seed oil" OR "wheat germ oil")

AND

(2) *Outcome* terms - ("price transm*" OR "price relat*" OR "price co-movement*" OR "price comovement*" OR "price co movement*" OR "price independenc*" OR "price dependen*" OR "price interdependenc*" OR "price dispersion*" OR "price volatilit*" OR "price regime*" OR "price inter-relationship*" OR "price interrelationship*" OR "price inter-relation*" OR "price interrelation*" OR "price pass-through" OR "price pass through" OR "price integration" OR "price link*" OR "price determin*" OR "price spillover" OR "price symmetr*" OR "price asymmetr*" OR "price shock*" OR "market integration" OR "law of one price" OR "LOP" OR "LOOP" OR "price signal*" OR "price pattern*" OR "price convergence" OR "spillover effect*" OR "symmetric price transmission*" OR "asymmetric price transmission*")

The same search string was used in most databases to ensure consistency apart from databases that had search limitations in which cases the search string was broken down and was used in different combinations (APPENDIX A).

The search in all databases produced 8019 studies. In addition to the database search, 107 studies were identified through basic Google search, references from relevant papers, ResearchGate and Taylor and Francis databases. A total of 8126 results were downloaded in RIS/Endnote and TXT format to enable double checking and were filed per database in folders. In databases were RIS/Endnote and TXT files were not available, such as from World Bank or hand-picked papers, PDF files were downloaded.

2.3.3.3 Screening strategy

The PRISMA flow diagram was followed to illustrate and report the flow of information and screening process *(Figure 15).*

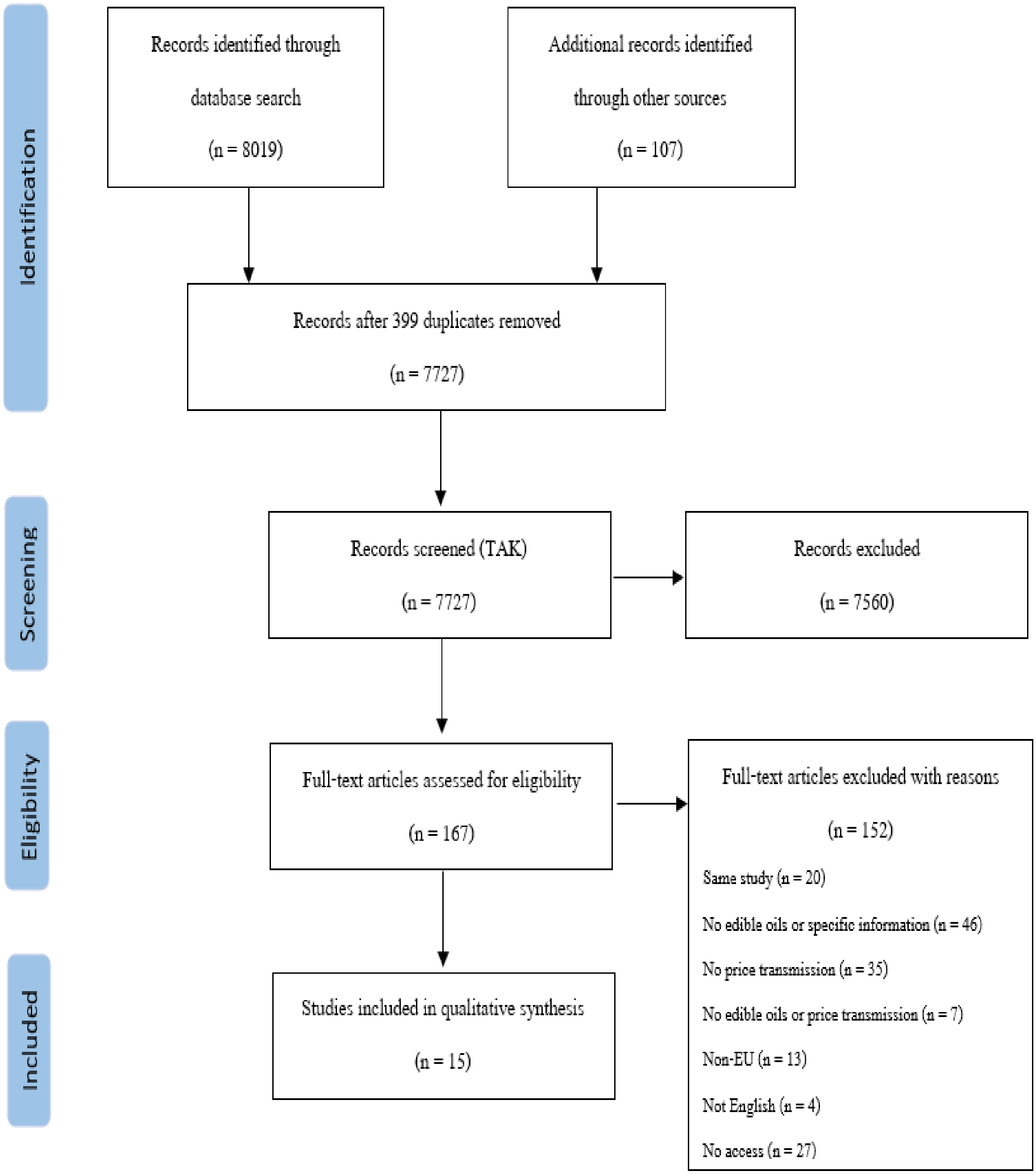


Figure 15. PRISMA Flow Diagram

Individual Endnote libraries (one for each database) were initially created and then were merged into a master Endnote library with all the results. This enabled a two-phase approach on removing duplicates. Phase one involved removing duplicates within each individual Endnote library due to multiple searches on some of the databases. Phase two involved removing duplicates in the master Endnote library to remove duplicates of studies that may have been published on multiple databases. A total of 399 duplicates were removed and 7727 articles remained for initial screening using a pre-determined set of inclusion and exclusion criteria that would establish the relevance of the results.

Inclusion criteria

Population - The study focuses on edible oil markets in European countries.

Outcome - The study involves the analysis of price dependence.

Exclusion criteria

Population – The study focuses on other agricultural commodities other than edible oils, or The study focuses on non-European countries.

Outcome – The study does not investigate price dependence.

Title-Abstract-Keyword (TAK) screening was conducted in the first instance where 7560 records were excluded, which led to 167 articles for full-text screening. The 167 articles included studies that met the inclusion criteria or studies where the potential relevance was unclear. In the full-text eligibility stage, 152 studies were excluded based on the exclusion criteria. Also, same studies were excluded at this stage. Same study was classed as a study that was published in two different article types/forms, e.g. same article was published in a journal but also presented in a conference. Finally, 15 studies were kept for further qualitative analysis. Studies that were excluded from all screening stages were categorised based on the topic area they studied, e.g. Medicine, Finance, etc.

2.3.3.4 Reliability – Validity

The steps undertaken to ensure the reliability and validity of data are presented in more detail in this section.

To achieve validity it was vital to ensure, from the beginning of the research, that a suitable model would be used to identify research gaps. Therefore, based on several previous studies (Katz *et al.*, 2003; Randall and James, 2012; Littell *et al.*, 2008; James *et al.*, 2016; Salama *et al.*, 2017; Soaita *et al.*, 2019), that were either directly related to the area of interest or to other disciplines, a systematic map was deemed appropriate to be implemented to meet the aims of this study. Further to the model, all elements that would be utilised during this process also had to be appropriate for the purpose. Thus, it was ensured that the search terms, databases and eligibility criteria that would frame this study were suitable for the examined discipline, topic area and commodity.

Moreover, reliability of the study was ensured with the engagement of a second researcher that helped to reduce research bias. In particular, a systematic mapping protocol was agreed and established at the start of the research, also including the search terms, databases, inclusion, and exclusion criteria to ensure consistency throughout the process. In addition, sample double screening (10%) was undertaken by the second researcher at all stages of the systematic mapping process, where any discrepancies were discussed and resolved. Other ways that contributed to the reliability of this study include the use of the PRISMA flow diagram to demonstrate the screening, clear presentation of the search terms, databases and search strings and concise record keeping allowing repeatability of this study.

2.3.4 Limitations of the systematic map

The results of this study are limited on the basis of the language of search, which was set as English only. This means that other significant studies that may have been published in Spanish, Italian or Greek were missed. This is a limitation since in the countries where olive oil is mainly produced, English is not the first language. However, researchers from these countries, also publish in English. In addition, the search was expanded to different types and multiple databases to reduce the likelihood of relevant articles being missed, while conference papers, research and review articles were also included. Another limitation is that the search focused on studies that were published between 1993 and 2020. The reason for excluding articles before 1993 was because the European Single Market was founded on January 1, 1993. Further research could be undertaken, extending the search in other languages such as Spanish, Italian, and Greek, or expanding the period and the focus to international markets.

2.3.5 Results of the systematic map

Through the identification, screening and eligibility stages of the Systematic Map tool, the final sample has been formed comprising of 15 studies that have investigated price dependence in the EU edible oil markets. This section will present the key findings from the 15 selected studies, which have been classified based on type of price transmission they focus on, i.e. studies investigating horizontal price transmission (HPT) (*Appendix B*), spatial price transmission (SPT) (*Appendix C*), vertical price transmission (VPT) (APPENDIX D), and price volatility transmission (PVT) (*APPENDIX E).*

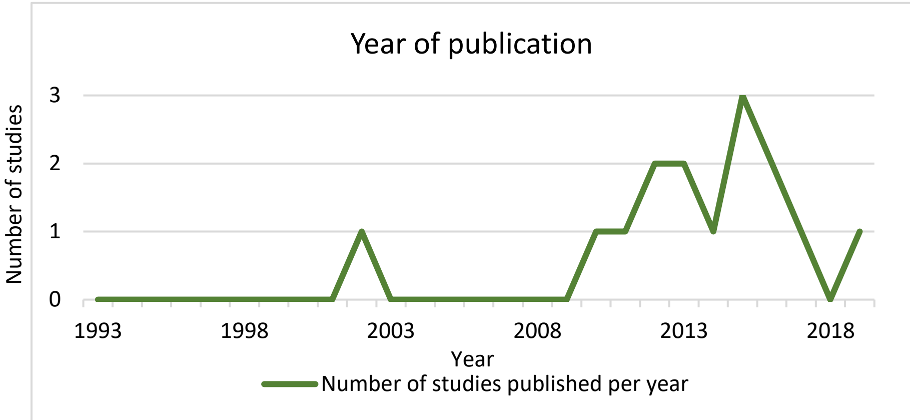
Key information has been extracted from these studies which will form the basis of further classification and analysis of the final sample. The key information includes study author/s, the product and countries under investigation, the type of price transmission examined, the methodology and data employed, and the study results. A cross-tabulation of the findings of each of the 15 selected studies is shown in *Table 4*. This table presents the studies with citations, the type of oil the investigate, the methods used and findings.

Table 4. Cross-tabulation of findings of Systematic Map results.

Article	Type of Edible Oil	Empirical Methods	Relationship between variables	Citations (Google Scholar)
Abdelradi and Serra 2015a	Biodiesel, Brent Oil, Rapeseed oil	Johansen Cointegration, VECM, MGARCH BEKK, DCC MGARCH	Positive relation between rapeseed oil and brent oil. No relation between rapeseed oil and biodiesel.	49
Abdelradi and Serra 2015b	Biodiesel, refined sunflower oil, crude oil	Johansen Cointegration, Engle and Granger Cointegration, Gregory and Hansen Cointegration, VECM, BEKK	Positive	37
Bergmann *et al.* 2016	Butter, palm oil, crude oil	VAR, GARCH, BEKK, Engle and Kroner, Hosking Multivariate Portmanteau (HM), Lagrange Multiplier (LM) tests, Wald tests	Positive relation between crude oil and butter before 2006. No relation between palm oil and crude oil before 2006, but after 2006 positive relation. No relation between butter and palm oil before 2006, but after 2006 positive relation.	34
Busse *et al.* 2012	Rapeseed oil, soy oil	Markov-switching VECM, Johansen Cointegration	Positive after 2006.	69
Emmanouilides *et al.* 2014	Extra virgin olive oil, lampante olive oil	Granger Causality, Copulas	Positive	15
Fousekis and Klonaris 2002	Extra virgin olive oil, Virgin olive oil	VECM, Forecast Error Variance Decomposition, Johansen Cointegration	Positive	8
Hamulczuka *et al.* 2019	Rapeseed oil	VECM, TAR, Johansen Cointegration, Forecast Error Variance Decomposition, Impulse Response Analysis	Positive	12
Hasanov *et al.* 2016	Crude oil, soybean oil, sunflower oil, rapeseed oil	GARCH, VAR-GARCH-in-mean-BEKK model, Impulse Response Analysis, Granger Causality	Positive	20
Hassouneh *et al.* 2012	Crude oil, refined sunflower oil	Johansen Cointegration, VECM, MLPR model	Positive	59
Panagiotou 2015	Extra virgin olive oil	Johansen Cointegration, VEC, GARCH-BEKK	Positive	3
Peri and Baldi 2010	Rapeseed oil, sunflower oil	Johansen Cointegration, TVECM, Exogeneity test	No relation between sunflower oil, soybean oil and diesel. Positive relation between rapeseed oil and diesel.	94
Serra and Zilberman 2013	Rapeseed oil, palm oil, soybean oil, sunflower oil	Literature Review	Positive relation between energy markets and food markets.	283

Tifaoui and Cramon Taubadel 2017	Butter	Engle and Granger Cointegration, VECM, Johansen Cointegration	Positive relation between retail and wholesale prices of butter.	22
Vacha *et al.* 2013	Gasoline, diesel, crude oil, corn, wheat, soybeans, sugarcane and rapeseed oil	Wavelet coherence analysis, Granger causality	Positive	107
Ziegelbäck and Kastner 2011	Rapeseed oil	TVECM, Balke and Fomby Threshold cointegration analysis	Positive	13

According to *Figure 16*, the trend in investigating market integration and price transmission in edible oil markets is fluctuating, with the least interest by researchers recorded between 1993- 2001 and 2003-2008. However, there has been an increase in research in this area over the last decade (2009-2019). More specifically, 93.3% of the articles were published from 2010 to 2019.



Year of publication	N
2002	1
2010	1
2011	1
2012	2
2013	2
2014	1
2015	3
2016	2
2017	1
2019	1
Total	15

Figure 16. Studies published from 1993 to 2019

The type of paper is shown in *Figure 17*. The total of 15 articles consisted of 13 research papers (86.66%), one review paper (6.67%) and one conference paper (6.67%).

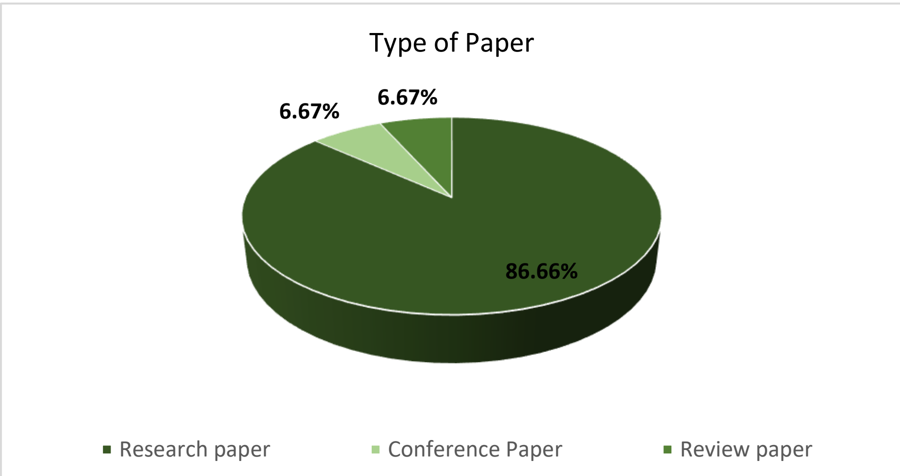


Figure 17. Type of Paper

Classifying the 15 studies of the literature based on the direction and type of price transmission, eight of the studies (53.34%) examined horizontal price transmission and two studies (13.33%) investigated vertical price transmission. Among the studies that analyse horizontal price transmission, the majority of them (five studies) analysed price relations between different agricultural commodities, while the remaining three examine price transmission between spatially separated markets. In addition, price volatility transmission was the focus of five studies (33.33%). The classification of studies in terms of the type of price relationship studied is shown in *Figure 18*.

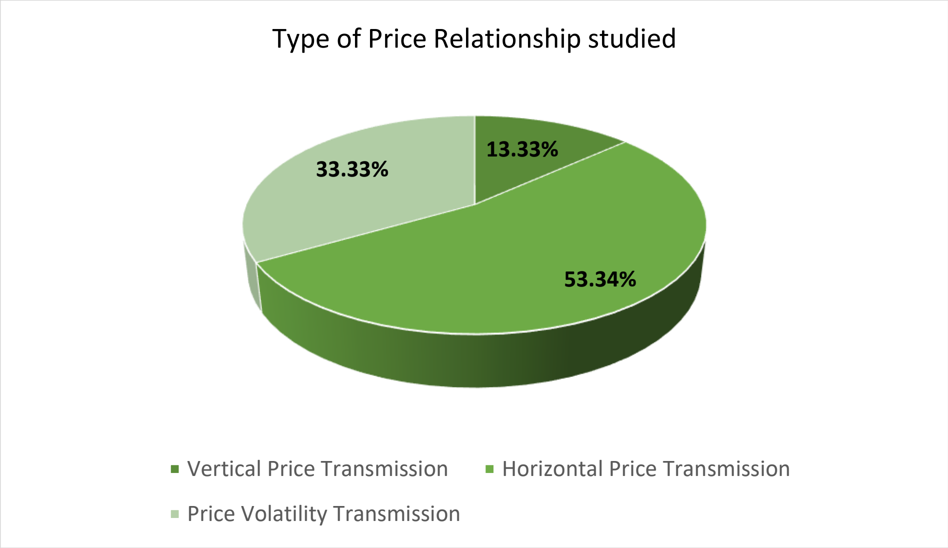


Figure 18. Type of price relationship studied

Figure 19 presents the distribution of studies in terms of the country studied. More specifically, out of the 15 studies, five articles (33.33%) investigated markets in Spain, followed by four articles (26.67%) that analysed the EU market as a whole, studies that examined markets in Italy, Greece and Germany were three each (20.00% each) and one of the papers (6.67%) focused on France. In addition, three articles (20.00%) investigated price relationships in edible oil markets between EU and non-EU countries.

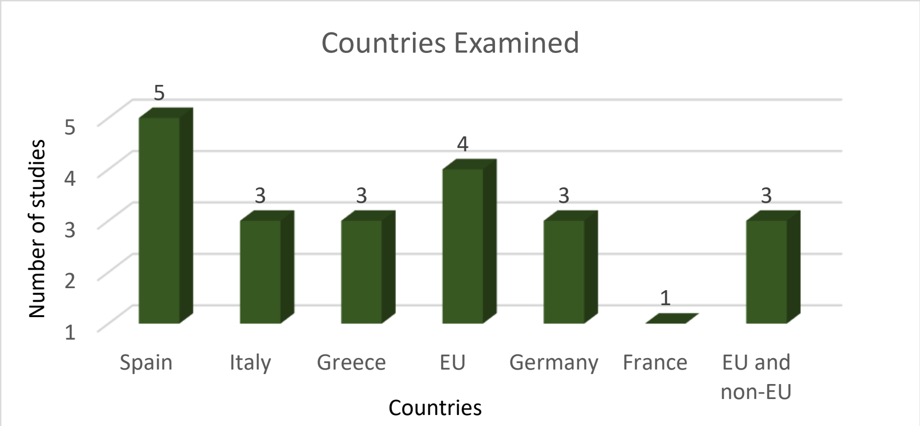


Figure 19. Countries examined

The frequency of various econometric methods employed for data analysis in the studies reviewed is presented in *Figure 20*. The most popular method employed was cointegration analysis. However, Vector Autoregressive (VAR) and Vector Error Correction Models were also common in studies related to edible oil markets and price relationships, followed by causality tests. Less popular tools are also shown in *Figure 20* and they include Autoregressive conditional heteroskedasticity (ARCH) and Generalised Autoregressive conditional heteroskedasticity (GARCH) models utilised in studies that investigated price volatility transmission, Impulse Response Function (IRF), structural changes and breakpoint tests, Ordinary Least Squares (OLS), and more recent methods, such as wavelets and copulas. More specifically, among the cointegration tests, most of the studies employed the Johansen test followed by Engle-Granger and Balke and Fomby cointegration tests. Finally, among the studies that investigated for linear or non-linear price behaviour in edible oil markets, most used ECMs, followed by Markov-Switching or Regime-Switching models and Threshold Autoregressive (TAR) model.

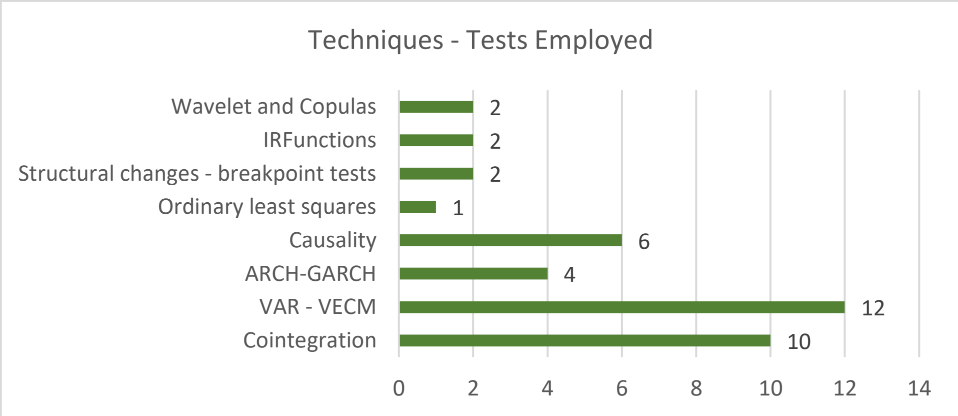


Figure 20. Selection of empirical tests employed in the studies

To perform the above empirical tests, studies employed various types of data. The frequency of data utilised in the included studies are shown on *Figure 21*. Particularly, eight of the studies (53.34%) utilised weekly data, three papers (20.00%) used monthly data, two studies (13.33%) performed the tests using daily data and one of the studies (6.67%) utilised both monthly and bi-weekly data for different regimes. Finally, one of the studies (6.67%) did not specify the frequency of the data used in their analyses.

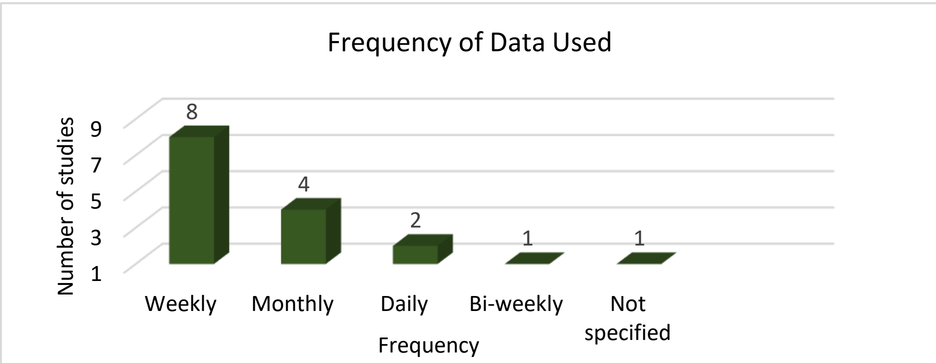


Figure 21. Frequency of data utilised in empirical studies

Another focus used for the classification of studies related to how price relations were evaluated. Thus, it was recorded whether authors test for: Market integration, the Law of One Price, Granger causality and price pattern. According to *Figure 22*, 11 of the articles (73.33%) tested for market integration in edible oil markets, and *Figure 23* shows that two of the studies (13.33%) tested for the Law of One Price. In addition, 11 of the papers (73.33%) did not test for Granger causality as per *Figure 24*, while 13 of the studies (87.00%) tested for non-linear patterns in price transmission as shown in *Figure 25*.

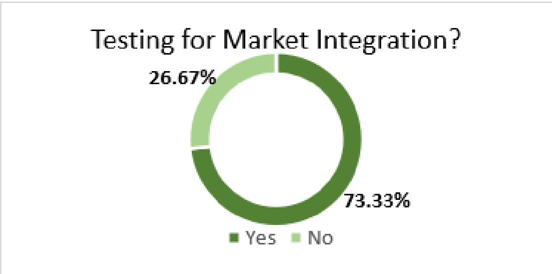


Figure 252. Percentage of studies that tested for market integration

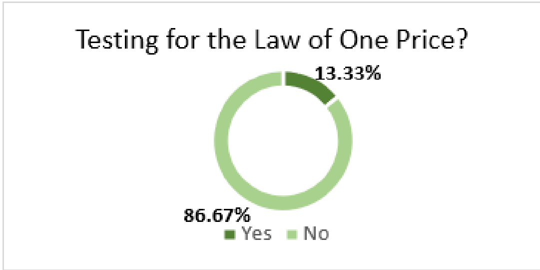


Figure 243. Percentage of studies that tested for the Law of One Price

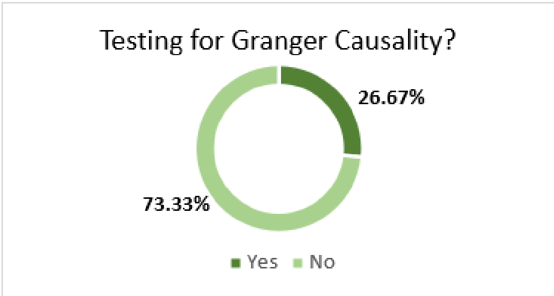


Figure 234. Percentage of studies that tested for Granger Causality

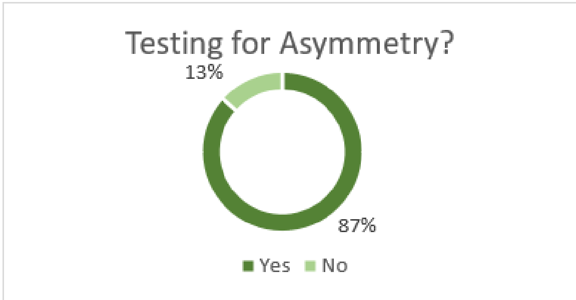


Figure 225. Percentage of studies that tested for asymmetries

The popularity of several vegetable edible oils is presented on *Figure 26.* The three most popular edible oil markets analysed in studies to investigate price relations, were rapeseed oil (eight studies), sunflower oil (five studies) and soybean oil (four studies). Less popular edible oils are also presented, such as olive oil (three studies) and palm oil (two studies).

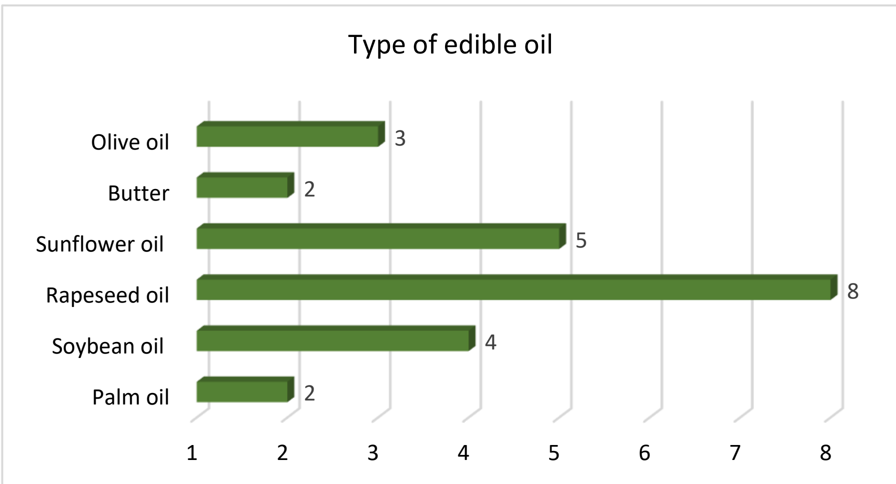


Figure 26. Type of edible oil analysed in the studies

Studies have also been classified to determinants of asymmetric price transmission *(Table 5).* The most common causes of asymmetries in the edible oil markets price mechanism included policies (four studies) and market power (three studies). Other less common causes include food crisis (two studies), temporary sales prices (one study), exchange rates (one study), stock practices (one study), substitutes (one study), financial crisis (one study) and unstable weather conditions (one study).

Table 5. Causes of Asymmetry

Factors affecting symmetry	Number of Studies
Policy/government intervention	4
Market power	3
Food crisis	2
Temporary sales prices	1
Exchange rates	1
Stock practices	1
Substitutes	1
Financial crisis	1
Unstable weather conditions	1

2.3.6 Discussion of the Systematic Map findings

This systematic map has compiled research articles documenting price dependence patterns in edible oil markets in the EU. Price transmission has been extensively examined in edible oil markets. However, this is mainly in relation to the energy markets. This is the reason an increase in the research in edible oil markets is deduced after 2009, which is in line with relevant policies that were introduced to encourage the use of biofuels. Edible oils that are directly related to the production of biofuels have been studied in terms of horizontal price transmission, including spatial, but also vertical price transmission. Prominent gaps in the evidence include the lack of research in the context of other edible oils that are not normally used in biofuel production, such as olive oil.

2.3.6.1 Market Integration in EU edible oil markets

The studies concluded in mixed results with regards to market integration. The majority of the studies provided sufficient evidence of market integration within the EU edible oil markets as well as between energy markets. In particular, Peri and Baldi (2010) analysed the long-run relationship between vegetable oils and diesel in the EU. The results showed a strong long-run relationship between rapeseed oil and diesel prices. Similarly, Vacha *et al.* (2013) confirmed price dependence between German rapeseed oil and diesel prices, which was supported also by Ziegelbäck and Kastner (2011) for the same markets in France. Hassouneh *et al.* (2012b) established a long-run relation between biodiesel, sunflower oil and crude oil prices in Spain; an outcome that has been further supported by Abdelardi and Serra (2015b). In the same vein, Abdelardi and Serra (2015a) also showed that EU rapeseed oil and biodiesel markets are integrated in the long-run.

However, when accounting for different regimes, Busse *et al.* (2012) found no evidence of price dependence between biodiesel (rapeseed oil and soy oil) and diesel prices before 2004 in Germany, whereas a strong relationship was established for the same markets after 2004. The mixed results in this case were due to the introduction of taxation on rapeseed oil, which led to an increase in the use of soy oil for the production of biofuels. Therefore, this policy strengthened the dependence between rapeseed oil and soy oil prices as substitutes. In addition, in the case of World and EU butter prices, Bergmann *et al.* (2016) found no relationship between the two markets before 2006, however the appeared to be integrated after 2006. The two regimes in this study were signified by the CAP Luxembourg agreement (2003), while 2006 was the threshold since the agreement required a couple of years to be fully implemented. Since the CAP Luxembourg agreement had a market orientation, the policies seem to have achieved the integration of the markets in this case. This shows that when considering agricultural markets within the EU, information flows freely since markets operate in line with common EU policies. In this vein, Sanjuán and Gil (2001) found a high degree of market integration in the EU pork and lamb markets, suggesting market efficiency.

On a spatial level, Hamulczuk *et al.* (2019) examined price transmission between Ukraine and the EU, using weekly prices, and suggested that rapeseed oil markets are cointegrated. Within the EU, the major olive oil markets i.e. Spain, Italy and Greece are also integrated (Fousekis and Klonaris, 2002; Emmanouilides *et al.*, 2014). Similar results were found in the EU dairy markets in relation to international markets, such as Oceania (Newton, 2016; Fousekis *et al.*, 2016; Fousekis and Grigoriadis, 2016a). Considering the difference in the level of perishability of the two agricultural products, i.e. rapeseed oil/ olive oil and dairy products, this result may seem relatively unexpected. This may be because, the less perishable a product is, the more stable the information flow may be between markets, whereas for more perishable products information may change more frequently, thus a less complete pass-through of information may be expected (Santeramo and Cramon-Taubadel, 2016; Hillen, 2021). In this case, markets of both products are found to be integrated, which may be due to EU CAP reforms to strengthen edible oil markets.

The efficiency of the edible oil markets has been implied in many studies as a result of a confirmed long-run relation and/or due to the high speed of shock transmissions between the markets. Therefore, evidence to support market integration are used to verify market efficiency. There is a limited number of studies though testing the validity of the Law of One Price, such as the study of Hamulczuk *et al.* (2019) who rejected the LOP for the EU and UA rapeseed oil markets due to asymmetries revealed as a result of market power exercised by traders in the UA market. Focusing on the EU markets, Fousekis and Klonaris (2002) confirmed similar findings for the olive oil markets and rejected the LOP due to the transportation costs being non-stationary (Fousekis and Klonaris, 2002). Another study that considered the LOP was conducted by Emmanouilides *et al.* (2014) who confirmed asymmetries in PT between olive oil markets; therefore, rejected the LOP by definition. In contrast to the edible oil markets, the LOP holds in EU pork markets (Emmanouilides and Fousekis, 2012) and EU broiler markets (Emmanouilides and Fousekis, 2014a). The validity of the LOP supports that the efforts made by the European Commission to integrate agricultural markets in the EU has been successful. However, in countries outside the EU such as Turkey such initiatives may not be present. This is confirmed by the results of Eryigit and Karaman (2011) who concluded that the LOP does not hold in the Turkish wheat markets.

Even though most of the studies concluded that EU edible oil markets are integrated with energy markets, there are some opposing views. Peri and Baldi (2010) showed that rapeseed oil and energy markets are integrated; however, they found no evidence of a long-run relationship in the case of sunflower seed oil and soybean oil prices with diesel prices. This may be explained by the fact that approximately 80% of biofuels in the EU are produced by rapeseed oil.

Overall, edible oil and energy markets are integrated and results from this systematic map are in line with the findings of the scoping literature developed by Serra and Zilberman (2013).

Noteworthy are the results of causal relationships between edible oils and energy markets. The vast majority of the studies concluded that edible oil markets affect energy markets (Busse *et al.*, 2012; Hassouneh *et al.*, 2012b; Vacha *et al.*, 2013; Abdelardi and Serra, 2015a; Abdelardi and Serra, 2015b), which may be explained by the fact that edible oils act as feedstock for the production of biofuels. However, there is limited evidence supporting the opposite direction which may be the case in the short run (Peri and Baldi, 2010; Hassouneh *et al.*, 2012b), following policy interventions in order to encourage the use of biofuels.

Evidence from the systematic analysis suggested that price linkages in the EU edible oil markets are measured through price data and mainly on a bivariate level, which is in line with the results from Goodwin (2006). In addition, a turn into non-linear techniques is shown in the latest years, such as threshold and regime models. Thus, the nature of spatial prices is considered, which based on Serra *et al.* (2006a; 2006b) is non-linear due to uncertainty, transaction costs and market distortions, which inhibits spatial arbitrage.

2.3.6.2 Market Integration in EU olive oil markets

In the context of EU olive oil markets, studies have presented mixed results as to the degree of market integration. Panagiotou (2015) suggested high dependence between major EU olive oil markets (Spain, Italy and Greece) and Fousekis and Klonaris (2002) further established a high degree of market integration between the same markets. However, Emmanouilides *et al.* (2014) concluded to a low degree of integration across the EU olive oil markets. The difference in the results may lie to several reasons. The utilised datasets differ in terms of the covered period, since Fousekis and Klonaris (2002) employed data from January 1992 to December 1998, whereas Emmanouilides *et al.* (2014) used more recent data from January 2002 to December 2012. Secondly, the empirical tests that were performed varied, whereby Fousekis and Klonaris (2002) utilised multivariate tests, whereas Emmanouilides *et al.* (2014) applied bivariate copula functions. Finally, the two studies examined different qualities/types of olive oil; these were extra virgin and virgin olive oils in the first case and extra virgin and lampante olive oils in the second case.

2.3.6.3 Pattern of PT in EU edible oil markets

The pattern of price transmission in the EU edible oil markets is confirmed to be asymmetric as supported by all the examined studies. Peri and Baldi (2010) confirmed the presence of asymmetry in terms of speed between rapeseed oil and diesel prices under different regimes. This asymmetry may be linked to global political agendas which resulted in policies to promote the use of biofuels. Similarly, Busse *et al.* (2012) established the presence of asymmetries between biodiesel and diesel prices in Germany considering different regimes, following the introduction of taxation on one of the main edible oils used for biofuel production; rapeseed oil. In addition, Hassouneh *et al.* (2012b) suggested asymmetries in terms of speed in the price transmission between sunflower oil and energy since biofuel prices adjust more quickly to deviations from the long-run equilibrium. This is attributed to exerted market power by the liquid fuels industry. Asymmetries were also present between the EU and UA rapeseed oil markets in the short run due to uncertainty in the production of rapeseed oil (Hamulczuk *et al.*, 2019). However, a symmetric pattern in terms of magnitude has been observed in the long run. Asymmetries have also been documented in studies where price spillovers were analysed. As such, negative shocks in rapeseed oil prices had a greater impact on biofuel price volatility than positive shocks (Abdelardi and Serra, 2015a; Hasanov *et al.*, 2016). The factors which led to asymmetries in the price spillover in rapeseed oil and biofuel markets were exchange rates, policy intervention, the food crisis and stock practices. Abdelardi and Serra (2015b) concluded to the same results for sunflower oil and biofuel markets. In particular, biodiesel prices appeared more sensitive to price decreases than increases while policy intervention, the food crisis and substitutability were recognized as the causes of this asymmetry. On a vertical basis, asymmetries were noted in the German butter market between retail and wholesale prices. Asymmetries resulted from temporary sales prices, such as when retailers introduce price promotions (Tifaoui and von Cramon-

Taubadel, 2017). This study contributed to literature surrounding asymmetry causes by introducing temporary sales prices as a determining factor.

2.3.6.4 Pattern of PT in EU olive oil markets

The EU olive oil markets are also characterised by asymmetric price transmission. This is confirmed by Emmanouilides *et al.* (2014), whereby for extra virgin olive oil asymmetries are present for the pairs Italy-Spain and Italy-Greece. Symmetry for this type of olive oil is only found in the case of Greece-Spain, since both markets constitute options for the Italian market that imports from them. Also, in the case of lampante olive oil asymmetry is detected only for the pair Italy-Spain, which may be due to a uni-directional price relationship. Fousekis and Klonaris (2002) also confirmed the presence of asymmetries in extra virgin and virgin olive oil price transmission and concluded that the EU olive oil markets are inefficient since the LOP was rejected by definition. Asymmetries in this case may be attributed to trade distortions (Meyer and Von Carmon-Taubadel, 2004), caused by Spain acting persistently as the main exporter and Italy as the main importer (Goodwin and Piggott, 2001; Fousekis, 2012). Finally, Panagiotou (2015) established asymmetric volatility spillover effects between Italy and Greece. This is due to Italy being highly dependent on Greek exports as they form a large percentage of Italian imports in bulk from which feed the Italian bottling industry.

2.3.7 Summary of Systematic Map findings

A systematic mapping approach was utilised to establish and collate evidence of price dependence in EU edible oil markets with a focus on EU olive oil markets. The database search was conducted on 12 databases and additional articles were collected independently. This search generated 8126 articles which underwent multiple stages of screening and resulted in 15 studies that met all the inclusion criteria. This process was illustrated with the use of the PRISMA diagram, and the studies were then classified based on the type of edible oil examined, type of data and methodology used, tests performed, countries examined and more. The majority of the studies were linked to energy markets, while only three referred exclusively to olive oil price relations despite the importance of the sector. The findings from the studies were then analysed and the results were mixed in terms of market integration and pattern of price transmission. Overall, EU edible oil markets appear to be well integrated both in the short run and the long run. Studies where market integration was confirmed were linked to policy intervention, which suggests that policies in energy markets strengthened price dependence, leading to market integration. Asymmetries are also a common phenomenon in the EU edible oil markets and the most important causes of asymmetry appeared to be policy intervention and market power. Moreover, asymmetries have been identified in the EU olive oil market suggesting lack of efficiency. Thus, it may be implied that the applied policies are not sufficient to eliminate market distortions. Mixed results were revealed for the EU olive oil market, whereby some studies suggested high degree of market integration while others lower, which is mainly explained by the different methodologies employed. Therefore, the need for further research is underlined to address weaknesses in existing studies.

2.4 Research Gap

To the best of knowledge, there is a limited number of studies which have analysed price relations within the Mediterranean countries and specifically olive oil prices (Fousekis and Klonaris, 2002; Emmanouilides *et al.*, 2014; Panagiotou, 2015). These studies do not draw clear conclusions in terms of market integration and provide mixed results. Therefore, a more systematic investigation is required in literature to reach more robust conclusions.

Also, the examination of price relationships has predominantly relied on econometric methodologies, with only two studies (Aragrande *et al.*, 2017; Acosta *et al.*, 2019) adopting a mixed-method approach to investigate various markets, albeit not with a specific focus on the olive oil sector.

In addition, current studies have analysed olive oil markets using econometric techniques that examine the long and short-run relations in separate systems, leading to information loss. In this respect, no study related to edible-olive oil markets has employed the non-linear asymmetric Autoregressive Distributed Lag (NARDL) cointegration technique developed by Shin *et al.* (2014), which allows long and short-run relationships as well the LOP to be tested simultaneously in a single and integrated system, minimising in this way potential disparities in the outcome.

Furthermore, while the direction of causality has been examined in various studies, these assume linearities in the price relations which may lead to false conclusions. Therefore, it is deemed crucial for this study to examine the direction of price relations of olive oils through non-linear and bootstrap causality tests which reduce bias, such as the ones proposed by Diks and Panchenko (2006; 2013) and Hacker and Hatemi-J bootstrap causality test (2010).

Moreover, existing literature regarding olive oil price transmission has not accounted for structural breaks and asymmetric price adjustment in the long and short run, which may be influenced by thresholds derived from transaction costs. The omission of these crucial factors may limit the ability to comprehensively understand the underlying dynamics of price transmission and the behavior of market participants.

Also, it is worth noting that studies that investigate the price relationships of olive oil often rely on a limited number of observations, although of high frequency, in their data samples. This highlights the need for studies employing more recent data that cover a wider period of time.

Overall, existing literature has reached mixed results in relation to market integration and price transmission in edible oil markets, while also indicating a gap for studies investigating olive oil markets in the Mediterranean. Therefore, it is crucial to identify and review the existing evidence of price patterns in the EU edible oil markets systematically and further confirm the research gap in the literature.

2.5 Conclusion of Literature Review Chapter

The review of literature indicated several studies that have investigated price transmission in the EU agricultural markets. However, these mainly refer to agricultural commodities produced and consumed primarily in Northern-European countries, with a limited number of studies related to the Mediterranean counties.

In addition, the systematic map confirmed that there is evidence of price dependence in energy related markets, such as edible oil markets. However, both the literature review and systematic map have confirmed the research gap for studies that analyse price relations in the EU olive oil markets, while existing studies provide mixed results regarding the pattern of price transmission across the EU edible oil markets and with regards to the olive oil ones. Furthermore, the methodologies used in existing studies do not take a mixed-method approach, they utilise separate systems to test long and short-run relations, and do not account for nonlinearities or structural breaks.

Therefore, this literature review has provided a summary of existing knowledge in the field, including what methodologies have been used and the findings, while the systematic map has helped to map relevant studies and establish the research gap. In combination, these elements provide the basis of this study.

Chapter 3 Conceptual Framework

This chapter organize and illustrate the key concepts and variables of the study, providing a roadmap for the research study and helping to clarify the relationships among variables by defining their operational definitions, including how they will be measured or quantified.

The study of prices provides a very powerful tool to understand market dynamics in terms of product availability and scarcity, stakeholder performance, relationship between stakeholders and distribution of welfare (Sexton and Lavoie, 2001). Focusing on the three pillars of market performance; the degree of market integration, the pattern of price transmission and the Law of One Price, prices are linked to Olive oil as they signal the stability of supply and demand, causality between the major olive oil producers and their performance. Increases in prices may indicate an increase in transaction or transportation costs or simply lower product availability in the case of droughts or production failures, whereas price fluctuations reflect their stability.

Several studies have studied the behaviour of prices to understand factors that affect them, as well as to identify possible patterns and the causes (Brummet, 2000; Baek and Koo, 2010; Parceli and Pierce, 2015; Baffes and Haniotis, 2016; DeLong and Trejo-Pech, 2022) . However, analysing the behaviour of prices in terms of how they are transmitted between markets or different stages in a supply chain can provide further insight into how effectively and efficiently a market operates, where the relationships are stronger or weaker, and why. While the price transmission process has been investigated extensively in the context of agricultural commodities such as meat (Bakucs and Ferti, 2006; Fousekis, 2015; Umar *et al.*, 2013), dairy (Chavas and Mehta, 2004; Rudinskaya and Boskova, 2021), as well as other edible oils such as groundnut oil (Sekhar, 2012), sunflower oil (Yu *et al.*, 2006) and more, only a small number of studies has focused on price transmission in the EU olive oil markets (Fousekis and Klonaris, 2002; Emmanouilides *et al.*, 2014; Panagiotou, 2015).

Expected Outcome

Overall, literature suggests that markets such as meat and dairy are very well integrated and efficient (Sanjuán and Gil, 2001; Fousekis, 2015), while other markets such as edible oils appear to be integrated but with asymmetries present in the price transmission process which indicates inefficiencies. With regards to EU olive oil markets in particular, the results from the existing studies are mixed in terms of market integration and the pattern of price transmission, while the Law of One Price is not empirically tested.

To provide a clearer picture of the price linkages in EU olive oil markets, this study investigates the price transmission process between the three principal EU virgin and extra virgin olive oil markets; namely, Spain, Italy and Greece by analysing market integration, causality, the pattern of price transmission and the Law of One Price. Based on existing literature and market overview, it would be expected that Spain or Italy would lead price formation and the price transmission process since they are the main exporter and importer, respectively, while Greece as a much smaller producer would be the price follower. Considering the interventions and initiatives that have been undertaken over the past few decades as outlined in the CAP to integrate and strengthen the olive oil markets, it would be expected that the olive oil markets in Spain, Italy and Greece would be very well integrated with very little asymmetries, and the Law of One Price would hold in its strong version. However, based on previous research that was carried out by Emmanouilides *et al.* (2014), Panagiotou (2015) and Theofanous (2015), asymmetries are expected in the price transmission process. Moreover, as stated in the market overview chapter, the market concentration (TekgüÇ, 2013), presence of market power (Abdulai, 2000; Bakucs *et al.*, 2013) , a consistently unidirectional relationship between the principal players (Goodwin and Piggott, 2001; Emmanouilides and Fousekis, 2012), government intervention (Gotz *et al.*, 2012; Emmanouilides *et al.*, 2014), and more provide indication of possible asymmetries in the EU olive oil market.

Based on theory and past research, the expected outcomes of this study are illustrated in *Figure* 27. Specifically, Spain is expected to be the central market and the price leader as the largest producer and exporter of olive oil (Fousekis and Klonaris, 2002; Theofanous, 2015). However, it is also expected that the highest degree of market integration between the countries will not be in a price pair that Spain is involved, but between Italy and Greece due to the closest geographical proximity and more intensive trading activity between the two countries. Nevertheless, Italy is also expected to play a crucial role in price leadership as the largest olive oil importer (Emmanouilides *et al.*, 2014).

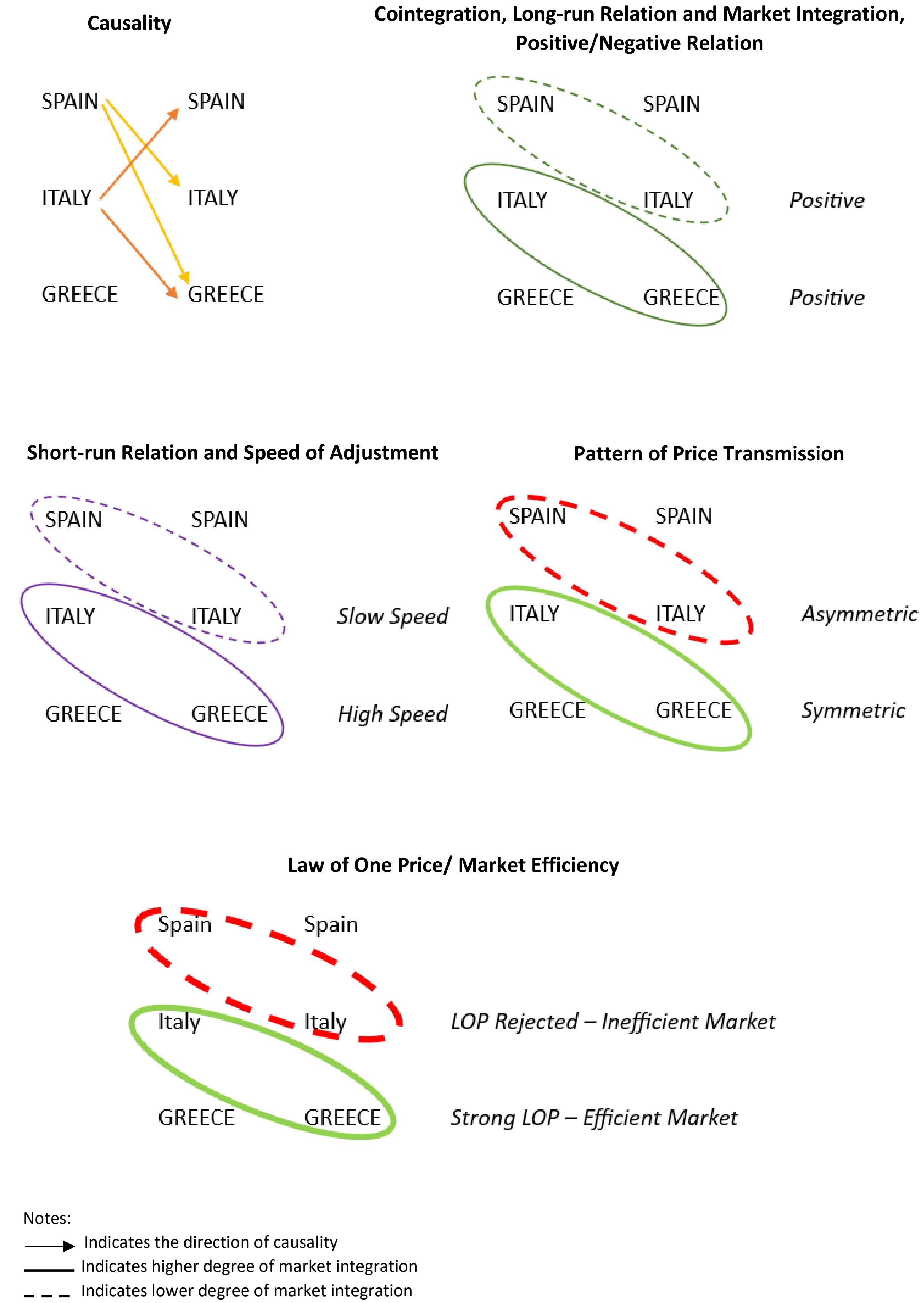


Figure 27. Expected outcomes of this study

Therefore, this study investigates each price relationship using empirical models to establish their position in the market as well as causality.

Research Roadmap

To do this, this study empirically analyses price data sets for two different qualities of olive oil; the two highest qualities of olive oil which are virgin and extra virgin olive oil. The data sets comprise of wholesale monthly prices of olive oil for the two qualities. Each principal olive oil producer country is employed in this study as a variable; independent or dependent variable depending on the empirical model. At the early stages, the variables of this study are examined through a multivariate model all together to understand which of the variables are related. Later, each country considered in this study is set as the independent variable at least once when investigating each relationship and also as dependent variables interchangeably, i.e. countries are examined in pairs in the later stage through bivariate models.

The datasets are converted into natural logarithms in the first instance in order to reduce skewness and normalise the data. The reason for using wholesale prices for this study, is in order to also account for transportation costs which according to literature play a very significant role in the price transmission process as suggested by Serra *et al.* (2006b). This is also in accordance with other studies that analysed price transmission in edible oil markets that also employ wholesale data (Fousekis, 2002; Hassouneh *et al.,* 2012; Emmanouilides *et al.,* 2014; Panagiotou, 2015; Bergmann *et al.,* 2016). The converted data is first tested to determine the order of integration which will then provide guidance as to which empirical models are more suitable to examine each dataset. This is done through a series of standard unit root tests, such as the Augmented Dickey and Fuller (1981) and Phillips – Perron (1988) tests, as well as unit root tests with structural breaks, such as the Perron (1989), Zivot-Andrews (1992) and Lee-Strazicich (2003) tests. Other researchers also use multiple unit root tests in their study to strengthen the validity of their results such as Sanjuán and Gil (2001), Balcombe *et al.* (2007), Esposti and Listorti (2013) and Fousekis and Trachanas (2016).

Following the determination of the order of integration of the data sets, the price pairs for VOO will be determined and test for the direction of causality, i.e. which country leads price formation, through the Diks and Panchenko causality test. This test was selected as it is a nonlinear causality technique. Nonlinearities are very common in agricultural commodity markets, for example due to transportation costs (Serra *et al.,* 2006b), and should therefore be considered when examining causality. Other researchers in the field also employed nonlinear models in their study, such as Emmanouilides *et al.* (2014) with the use of copulas. Once this is completed, a bivariate cointegration test, the one proposed by Engle and Granger, will be employed to investigate the long-run relationship between the variables as well as a second cointegration technique which also considers structural breaks, such as the one proposed by Gregory and Hansen (1996) to further confirm the results. This step will confirm whether the pairs are cointegrated which also means that a price shock in one variable causes a price shock in the other variable, thus confirm the presence of the price transmission process. Therefore, the next step will involve the examination of the pattern of the price transmission process through the Momentum Threshold Autoregressive (MTAR) test to identify possible asymmetries in the relations as suggested by Serra and Goodwin (2003) and Gizaw *et al.* (2021). If asymmetries are confirmed in some or all of the pairs then the Law of One Price is rejected by definition and an Error Correction Model can be applied to examine the short-run relations between the asymmetric pairs as suggested by Fousekis and Klonaris (2002). However, if in any or all price pairs symmetry is confirmed then this will allow the Law of One Price to be empirically examined through a Wald test.

In the case of EVOO price data, the Hacker and Hatemi (2010) bootstrap causality test will be employed to test causality between the variables, which is also a nonlinear causality test and has been used by other researchers in the agricultural commodity field (Fousekis and Trachanas, 2016; Panagiotou, 2021). Following the confirmation of the direction of causality between the variables, the bivariate and bi-directional ARDL Cointegration test will be utilised to test the long-run relationships between the variables, followed by the Diks and Panchenko (2006) causality test. Furthermore, the NARDL cointegration model will be applied to test for cointegration and asymmetry under one single equation; this strengthens the validity of the results as potential discrepancies that could occur if these were tested under different equations are eliminated. The NARDL model tests for both long-run and short-run asymmetry and has also been employed by other researchers in the field including Fousekis and Trachanas (2016), Fousekis *et al.* (2016) and Abdalla *et al.* (2020).

Diagnostic tests will be applied throughout both empirical sections to ensure the suitability and stability of the models employed in this research to further strengthen the validity of the findings.

Chapter 4 Empirical Analysis on Price relations in EU olive oil markets

4.1 Introduction

The rise in consumer demand for olive oil worldwide and within the EU has prompted the key players in this market to manage olive oil production in order to meet this demand. The increase in demand, however, is predominantly driven by the higher-quality olive oils, including virgin (VOO) and extra-virgin olive oil (EVOO). According to the literature, the health benefits associated with olive oil are primarily attributed to the lower acidity levels present in VOO and EVOO. Specifically, olive oil is classified as VOO if its acidity does not exceed 2%, while EVOO refers to olive oil that contains less than 0.8% acidity (IOC, 2022b). Literature suggests that the health benefits offered by olive oil are associated with the lower acidity levels that VOO and EVOO contain. Specifically, olive oil can be described as VOO is it does not exceed 2% acidity, whereas EVOO describes the olive oil which does not exceed 0.8% acidity (IOC, 2022b).

Therefore, this is also reflected in the share of production in the EU principal olive oil markets that VOO and EVOO own. For example in Spain, while the majority of olive oil production is of virgin quality, 30% of olive oil production corresponds to EVOO (Mylonas, 2015). Regarding Italy, the majority of olive oil produced (60%) is of extra virgin quality (Rossi, 2017). However, out of the three principal olive oil markets, Greece's share of extra virgin olive oil is the biggest, whereby more than 80% of Greece's olive oil production is of extra virgin quality (Mylonas, 2015). In terms of consumption in the three principal olive oil markets, EVOO is also the number one preference of domestic consumers (Statista, 2022a).

Recent literature also examined different qualities of olive oil; however, this is mainly considered from a consumer's viewpoint. For example, Carbone *et al.* (2018) employed panel data for EVOO from Italian regions over three production years (2012-2014) and a hedonic price model to examine the role of different olive oil qualities in creating value for consumers in high segments of the Italian olive oil market. Consumers were found to value more product characteristics, raw materials, and the production process, whereas they feel that product origin and organic production do not provide additional value. Contrastingly, Carzedda *et al.* (2021) performed a choice experiment with 1000+ participants and found that there is a positive consumer preference for origin characteristics, while organic characteristics are not highly valued among consumers in Italy. This study used questionnaires to quantify Italian consumers' willingness to pay for EVOO resulting from organic production, and EVOO based on geographical origin. Another study on consumer preferences of olive oil qualities was conducted by Di Vita *et* *al.* (2021), however this study aimed to segment consumers in Italy into consumer target groups for specific olive oil qualities. This was pursued through anonymous questionnaires and interviews of 330 participants in Milan and Turin, which were analysed through factorial and cluster analysis. Findings identified three main classes of olive oil consumers based on olive oil quality. The first class was described as "basic" quality class of olive oil consumers and involved families of medium to large sizes. Consumers that fall in this segment exhibit higher consumption of more affordable olive oil qualities. The second class was "popular", which involves consumers that prefer private labels and famous brands through retail stores, primarily. These consumers show a preference to olive oils of mild taste. The third and last class that they identified was "premium". Consumers in this segment prefer olive oil of stronger sensory characteristics and geographical origin. A very limited number of studies have also examined price relationships of particular olive oil qualities, such as Panagiotou and Stavrakoudis (2021) and Fousekis (2022). Panagiotou and Stavrakoudis (2021) investigated price dependence in EVOO markets in Spain, Italy, and Greece. Through the use of wavelets and copulas, they confirmed that there is stronger price dependence between the principal olive oil markets in the long run than in the short run. Also, they found asymmetric price comovement whereby EVOO prices in Spain, Italy, and Greece are more likely to crash together than to boom together. Finally, Fousekis (2022) explored price risk connectedness in EVOO and VOO markets in Spain, Italy, and Greece. Through econometric analysis, Spain was found to be the central market, and risk connectedness appears stronger following positive shocks than negative shocks. In addition, olive oil of lower quality, e.g. VOO, is less likely to transmit price risk to higher olive oil qualities, e.g. EVOO. Similarly, price risk is easier transmitted from larger markets, e.g. Spain and Italy, to smaller markets, e.g. Greece. These studies supported that different qualities of olive oil can exhibit different price behaviours and influence consumer preferences.

In this respect, this chapter will present an examination of the price relations in olive oil markets in Spain, Italy and Greece focusing on the two highest qualities of olive oil; VOO and EVOO. Specifically, the degree of market integration will be examined ***(OBJECTIVE TWO)***, and the long-run and short-run relations between the principal virgin and extra virgin olive oil markets in the EU will be analysed ***(OBJECTIVE THREE)***. In addition, the present chapter will determine the pattern of price transmission ***(OBJECTIVE FOUR)*** and investigate the efficiency of the principal virgin and extra virgin olive oil markets in the EU ***(OBJECTIVE FIVE).*** A methodology section will be presented, that will be common for both parts of the empirical analysis of this chapter, which will introduce all data, and methods and techniques that were utilised in this empirical examination. This will include the unit root tests: ADF, PP, Zivot-Andrews and Lee-Strazicich; cointegration tests: Johansen, Engle-Granger, Gregory-Hansen, ARDL and NARDL; causality tests: Diks and

Panchenko, Hacker and Hatemi-J bootstrap; symmetry tests: MTAR, ECM. This will be followed by two sub-sections; one for VOO and one for EVOO. Each sub-section will begin with some descriptive statistics and continue by presenting the empirical test and the results. The findings for each sub-section will be discussed and summarised in a single chapter. The reason for this is because, while each sub-section is analysing a different quality of olive oil, the purpose is to provide insight to price relations in the olive oil market as a whole and the use of the two highest qualities of olive oil aims to act as representative of the entire market. In addition, different techniques were used to analyse each type of olive oil. The rationale behind this is two-fold; on a first basis, the order of integration of each dataset determined the different set of tests used, and on a second basis leveraging the distinct strengths of each method offset possible limitations, thus enhancing the comprehensive interpretation of the results.

4.2 Methodology

This chapter presents the data and econometric models that were employed for the empirical analysis of this study. The aim of this chapter is to examine spatial price relationships between the three major EU olive oil markets (Spain, Italy, and Greece) with focus on virgin (VOO) and extra virgin olive oil (EVOO) qualities. The empirical methodology was structured as follows; unit root tests have been carried out to establish the order of integration between the examined variables, cointegration techniques were used to test for any long-run relationships as well as causality tests to understand the direction of causality between variables. In addition, the pattern of price transmission has been examined through a variety of models and the Law of One Price was tested where possible. All employed econometric techniques are introduced in this chapter.

4.2.1 Unit root Tests

4.2.1.1 Augmented Dickey Fuller (1981) Unit Root Test (ADF)

The ADF test by Dickey and Fuller (1981) is the ‘augmented’ or evolved version of the Dickey-Fuller unit root test (Dickey and Fuller, 1979) and it is one of the most common tests that examines the integration order of time series data in terms of stationarity. The null hypothesis supports the existence of a unit root in the examined time series, whereas the alternative hypothesis of no existence of a unit root in the series implies stationarity. In essence, stationarity denotes that a time series possesses a fixed mean and variance that remain constant over time. While the null hypothesis is the same for both the original and the augmented versions of this test, the ADF (Dickey and Fuller, 1981) test accounts for more differencing terms. Said and Dickey (1984) have further included lags of the dependent Δ_y, to eliminate autocorrelation of the residuals (Kulaksizoglu, 2015; Paparoditis and Politis, 2018).

For the application of the test, it is required to determine whether the examined sample will include a constant or intercept, a linear time trend or a combination of both.

Specifically, equation (5.1) presents the model without an intercept and time trend,

$$\Delta y_t = a y_{t-1} + \sum_{i=1}^{k} \gamma_i y_{t-i} + \varepsilon_t \text{ (5.1)}$$

equation (5.2) presents the sample with an intercept, without time trend,

$$\Delta y_t = c + a y_{t-1} + \sum_{i=1}^{k} \gamma_i y_{t-i} + \varepsilon_t \text{ (5.2)}$$

and equation (5.3) presents the model with an intercept and time trend.

$$\Delta y_t = c + a y_{t-1} + \sum_{i=1}^{k} \gamma_i y_{t-i} + \beta_t + \varepsilon_t \text{ (5.3)}$$

Where *k* denotes the optimal number of lags for the dependent variable Δ_y in each sample. The optimal lag length is determined using Information Criteria. The statistic of the ADF unit root test is calculated through equation (5.4):

$$\Delta y_t = (\alpha - 1) y_{t-1} + \sum_{i=1}^{k} \gamma_i \Delta y_{t-i} + \varepsilon_t \text{ (5.4)}$$

The tests give a t-statistic that is compared against the critical values set out MacKinnon (1996). The critical values correspond to significance levels 1%, 5% and 10% which indicate the levels of confidence that the null hypothesis can be-rejected. The rejection of the null hypothesis on any confidence level depends on how negative the value of the given statistic is. Therefore, the rejection of the null hypothesis of existence of a unit root is more powerful when the t-statistic is more negative. In other words, when the t-statistic is greater that the critical values at 1%, 5% and 10% significance levels, then the null hypothesis cannot be rejected and the price data is considered non-stationary, hence the existence of a unit root is confirmed. Conversely, when the t-statistic is smaller than the critical values, the alternative hypothesis of no existence of a unit root is confirmed.

A necessary condition for the rejection of the null is that the lag length is specified, which can be achieved through the application of selection criteria such as the Schwarz, Akaike, or Hannan-Quinn information criterion. The rejection of the null hypothesis at significance levels 1% and 5% gives more confidence that the results are valid compared to when the null hypothesis is rejected based on the critical value at 10% significance level.

4.2.1.2 Phillips-Perron (1988) Unit Root Test (PP)

The Phillips-Perron unit root test was developed by Phillips and Perron (1988) and is very similar to the ADF unit root test. The main difference between the two tests is in the way they address heteroskedasticity in the errors and serial correlation; particularly, the PP

(1988) unit root test overlooks serial correlation in the test regression. It is based on a non-parametric error factor that estimates the fluctuation of errors. The null hypothesis of the PP unit root test (Phillips and Perron, 1988) supports the existence of a unit root, whereas the alternative hypothesis suggests that a unit root does not exist in the examined series. Similar to the ADF test (Dickey and Fuller, 1981), the PP test (Phillips and Perron, 1988) requires the determination of whether the model will include an intercept and/or trend or neither of the two.

The following equation (5.5) illustrates the model without an intercept and trend:

$$\Delta Y_t = \alpha Y_{t-1} + U_t \quad (5.5)$$

Equation (5.6) presents the model with an intercept and no trend, while equation (5.7) demonstrates the model with both an intercept and trend:

$$\Delta Y_t = c + \alpha Y_{t-1} + U_t \quad (5.6)$$

$$\Delta Y_t = c + \alpha Y_{t-1} + \delta_t + U_t \quad (5.7)$$

The statistic of the PP unit root test is calculated through equation (5.8):

$$t_{pp} = t_\alpha \left(\frac{y_0}{f_0}\right)^{1/2} - \frac{T(f_0 - \gamma_0)s_\alpha}{2f_0^{1/2}s} \quad (5.8)$$

Where, t_α denotes the t-statistic, s_α represents the standard error that derives from the above equations, s equals to the standard error of the test regression, T represents the sample size and γ_0 corresponds to the estimation of error fluctuation.

For the application of this test, determining the lag length is a necessary condition and this can be set by using criteria such as the Schwarz, Akaike, or Hannan-Quinn information criterion. The test gives a t-statistic which is compared with the corresponding critical values at significance levels 1%, 5% and 10% which determine whether the null hypothesis can be rejected or not. The critical values derive from Dickey and Fuller (1979).

4.2.2 Unit root tests with structural breaks

4.2.2.1 Perron (1989) unit root test with one structural break

Perron (1989) was the first to propose a unit root with one structural break. This test was developed considering that the standard unit root tests, such as ADF, cannot reject the null hypothesis when there is a structural break in the examined time series. Therefore, based on Perron (1989) the standard tests support that the examined series are non-stationary even though there is unit root at a different angle.

The time of the structural break in the Perron (1989) test does not depend on the data; in other words, it happens exogenously. For the unit root test with one structural break a modified ADF t-statistic is used, with break in the intercept and/or trend through dummy variables. According to Perron (1989), when the structural break occurs during the point in time T_z, the model with break in the intercept is presented as (5.9):

$$\Delta Y_t = a_0 + a_1 D_t + a_2 D(T_z)_t + \beta Y_{t-1} + \sum_{i=1}^{k} \gamma_i Y_{t-i} + u_t \quad (5.9)$$

where D_t denotes the dummy variable which is equal to 1 when t is greater than the time of the structural break, whereas it is equal to 0 when t is smaller than the time of the structural break. Also, $D(T_z)_t$ is equal to 1 when t is equal to $T_z + 1$, otherwise it is equal to 0.

The model with break in the trend is presented as (5.10):

$$\Delta Y_t = a_0 + a_1 DT_t + \beta Y_{t-1} + \sum_{i=1}^{k} \gamma_i Y_{t-i} + u_t \quad (5.10)$$

where D_t denotes the dummy variable which is equal to $t - T_z$ when t is greater than the time of the structural break, whereas when t is small than the time of the structural break, then it is equal to 0.

The model with break in both the intercept and trend is presented in equation (5.11):

$$\Delta Y_t = a_0 + a_1 D_t + a_2 D(T_z)_t + a_3 DT_t + \beta Y_{t-1} + \sum_{i=1}^{k} \gamma_i Y_{t-i} + u_t \quad (5.11)$$

where D_t denotes the dummy variable which is equal to 1 when *t* is greater than the time of the structural break, whereas it is equal to 0 when *t* is smaller than the time of the structural break. Also, $D(T_z)_t$ is equal to 1 when *t* is equal to $T_z + 1$, otherwise it is equal to 0. Furthermore, DT_t is equal to $t - T_z$ when *t* is greater than the time of the structural break, whereas when *t* is smaller than the time of the structural break, then it is equal to 0.

The structural break can occur both in the null hypothesis and the alternative hypothesis. The corresponding critical values are provided by Perron (1989) and are determined at each time period of the structural breaks.

4.2.2.2 Zivot-Andrews (1992) unit root test with one structural break

Zivot and Andrews (1992) developed a unit root test that accounts for one structural break, however as opposed to the Perron (1989) test whereby the time of the structural break is an exogenous factor, the Zivot-Andrews (1992) test propose that the structural break will be determined endogenously through the data.

The Zivot and Andrews (1992) unit root test utilises a dummy variable in the price series where a structural break is identified. A necessary condition to perform this test is the determination of whether the model will include a break in the intercept and/or the trend. In addition, the optimum lag length is selected using Information Criteria, such as Akaike or Schwarz Info Criterion or Hannan-Quinn. The null hypothesis supports that a unit root exists in the price series, whereas the alternative hypothesis suggests that a unit root does not exist in the price series with one structural break.

Equation (5.12) illustrates the model with break in the intercept:

$$\Delta Y_t = a_0 + a_1 D_t + \beta Y_{t-1} + \sum_{i=1}^{k} \gamma_i Y_{t-i} + u_t \quad (5.12)$$

Where D_t represents the dummy variable of the break in the intercept. The dummy variable equals 1 when t is greater that then structural break T during period t, whereas in the case where t is smaller than T_t, the dummy variable equals 0.

Equation (5.13) presents the model with break in the trend:

$$\Delta Y_t = a_0 + a_1 DT_t + \beta Y_{t-1} + \sum_{i=1}^{k} \gamma_i Y_{t-i} + u_t \quad (5.13)$$

Where T_t denotes the structural break during time period t and DT_t denotes the dummy variable of the break in the trend. The dummy variable equals t-T_t, when t is greater than the structural break value in the time period t whereas it equals 0 when t is smaller than the structural break in time period t.

Finally, equation (5.14) describes the model with break in the intercept and trend:

$$\Delta Y_t = a_0 + a_1 D_t + a_2 DT_t + \beta Y_{t-1} + \sum_{i=1}^{k} \gamma_i Y_{t-i} + u_t \quad (5.14)$$

Where D_t and DT_t are defined as the dummy variables of the breaks in the intercept and trend respectively. D_t equals to 1 when t is greater than T_t, while in the case where t is smaller than T_t, the dummy variable equals 0. Also, D_t is equal to t-T_t when t is greater than the structural break in time period t, while D_t equals 0 when t is smaller than the structural break in time period t.

The time of the structural break is identified at the point where the estimated t-statistic of the test demonstrates the most negative value. The corresponding critical values of the test are provided by Zivot and Andrews (1992) and are determined by the respective time period of the structural breaks.

4.2.2.3 Lee-Strazicich (2003) unit root test with two structural breaks

Lee and Strazicich (2003) suggested a unit root test which allows for up to two structural breaks and determines the time of the structural breaks endogenously from the data. The null hypothesis supports that the series has a unit root with break, whereas the alternative hypothesis suggests that the series does not have a unit root with break.

For the application of the test, the Lagrange Multiplier (LM) statistic is used, and it needs to be pre-determined whether the model will include a break in the intercept or in the intercept and trend. In the case where a structural break happens in time T_z, the model equations (5.15 and 5.16) are as follows:

$$\Delta Y_t = a_0 + a_1 D_t + a_2 D(T_z)_t + \beta Y_{t-1} + \sum_{i=1}^{k} \gamma_i Y_{t-i} + u_t \quad (5.15)$$

$$\Delta Y_t = a_0 + a_1 D_t + a_2 D(T_z)_t + a_3 DT_t + \beta Y_{t-1} + \sum_{i=1}^{k} \gamma_i Y_{t-i} + u_t \quad (5.16)$$

Equation (5.15) presents the model with intercept and equation (5.16) illustrates the model with intercept and trend. Specifically, D_t denotes the dummy variable which is equal to 1 when t is greater or equal to T_z+ 1 for one or two structural breaks, whereas in the opposite case the dummy variable is equal to 0. Also, DT_t represents the dummy variable oft he break with trend and is equal to t-T_z when t is greater than T_z+1 for one or two structural breaks, whereas in the opposite case the dummy variable is equal to 0.

The times of the structural breaks are identified at the points where the estimated t-statistics of the test demonstrate the most negative values. The test requires the optimal lag length *k* to be set, and this is achieved by taking an approach where the lag lengths are tested from the larger to the smallest lag length, as suggested by Lee and Strazicich (2003). Finally, the corresponding critical values originate by Lee and Strazicich (2003).

4.2.3 Cointegration Analysis, Error Correction models and Causality Tests

After conducting a series of unit root tests to identify the presence of a unit root in the price series and to explore the order of integration, the subsequent step entails ascertaining the existence of a steady, long-term relationship between the variables. When there is cointegration and therefore long-run relation between a pair of variables, the prices tend to comove, following a common trend. In the short run, however, the prices may diverge considering that shocks in one variable may not be transmitted instantly to the other variables.

Long-run relations between variables are tested through different cointegration techniques such as the one by Engle and Granger (1987), Johansen (1988), Phillips and Ouliaris (1990) and Dynamic Ordinary Least Squares – DOLS (Saikkonen, 1991). Both the Engle-

Granger (Engle and Granger, 1987), and Phillips-Ouliaris (Phillips and Ouliaris, 1990) and the Autoregressive Distributed Lag (ARDL) cointegration tests involve a requirement for the determination of the dependent and independent variable which may lead to false conclusions if the choice of the dependent variable is wrong. The Phillips-Ouliaris test is an improvement of the Engle-Granger test in terms of the weight they place on the residuals which are used to perform both tests. Specifically, while the Engle-Granger test does not account for possible variance in the residuals, the Phillips-Ouliaris test recognizes that the residuals are estimates and not real parameters (Rao, 1994).

4.2.3.1 Johansen (1988) Cointegration Test

In addition, Johansen (1988) cointegration test addresses the main issue of the Engle-Granger test by avoiding the requirement to select the dependent variable (Agunloye *et al.*, 2014). Johansen's (1988) cointegration test takes a multivariate approach and identifies the number of cointegrating vectors between the examined variables. The number of cointegrating vectors indicates the number of long-run relationships in the sample in pairs, which can then be used to determine the causal relationships. A necessary condition to perform this test is that the examined variables are integrated of order 1, I(1), i.e. they are stationary in the first differences. Initially, a VAR model which includes the first differences is estimated through the selection of the optimal lag length to be determined through selection criteria such as Schwarz or Akaike Information Criteria. The VAR model is estimated as follows (5.17):

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta Y_t + ZX_t + u_i \quad (5.17)$$

Where, Π denotes the equilibrium matrix which includes information regarding the long-run equilibrium relations, whereas r represents the number of cointegrating vectors. Johansen (1988) provides the error correction and cointegration models based on Maximum Likelihood (ML).

The estimation of the model based on Johansen (1988) and Johansen and Juselius (1990) proposes two cointegration rank tests, namely the trace test and the maximum eigenvalue test. Both tests provide information regarding the number of cointegrating vectors present in the examined series. The maximum eigenvalue test examines the null hypothesis of the existence of r vectors against the alternative hypothesis of r+1 vectors identified in the examined series, whereas the trace test examines the null hypothesis of existence of at most r vectors. To test the hypotheses, the two tests produce a Trace statistic and a Max-Eigen statistic, respectively, which are compared against the given critical values, and p-values provided by MacKinnon-Haug-Michelis (1999). When the Trace statistic or Max-Eigen statistic exceeds the critical values at 1%, 5% or 10% significance level, then the null hypotheses of no cointegrating vector or the existence of at most 1 cointegrating vector can be rejected, whereas when the t-statistics are smaller than the critical values at 99%, 95% or 90% confidence level, then the null hypotheses cannot be rejected.

On the one hand, the Johansen test is considered one of the most reliable cointegration tests for the investigation of long-run relationships considering that it identifies the exact number of cointegrating vectors in a multivariate framework. It also allows for the designation of relations among the examined variables and is based on endogenous variables (Gonzalo and Lee, 1998). On the other hand, since the test is based on VAR models, misleading regarding the existence and number of cointegration relationships may result if the sample size is small and the inappropriate lag length is selected.

The Johansen cointegration test is one of the most popular cointegration techniques used across a variety of different topics such as to business and health and safety (Ivascu *et al.*, 2021), economic growth (Babatunde and Adefabi, 2005), finance markets (Maggiora and Skerman, 2009), price transmission in agricultural commodity markets (Babiker and Abdalla, 2009) and Koutroumanidis *et al.*, 2009; Weldesenbet, 2013; Chen and Saghaian, 2016; Mumtaz and Naresh, 2017),and more.

4.2.3.2 Engle and Granger (1987) cointegration test

Engle and Granger (1987) proposed a cointegration test that is commonly utilized. However, it is a bivariate test, which implies that it can only be applied between two variables and is limited to determining a maximum of one cointegrating vector. This constitutes a limitation of the test as it requires the prior determination of the role of the two variables. Additionally, because this is a two-step model, any disparities from the first step may be carried over to the second step of the test, potentially leading to spurious conclusions. Nevertheless, this test is generally simple to apply, and the error correction model can accommodate an extended number of lags.

A preliminary stationarity test is firstly applied to examine whether the time series have a unit root. To obtain the parameter values, the OLS autoregression cointegration test is applied through model (5.18). This is followed by isolation of the errors that are also tested for stationarity through the application of the ADF test, with no constant or/and trend, to the autoregressive model (5.19).

$$\Delta y_t = C + \beta x_t + u_t \text{ (5.18)}$$

$$\hat{u}_t = \psi \hat{u}_{t-1} + v_t \text{(5.19)}$$

When u is stationary, then the time series are considered cointegrated. However, if the error term has a unit root, then the model should be performed with the first differences.

The cointegration parameters are then estimated and the error term is added to the error correction model as per equation (5.20):

$$\Delta y_t = \beta_1 x_t + \beta_2 \hat{u}_{t-1} + v_t \text{ (5.20)}$$

where:

$$\hat{u}_{t-1} = y_{t-1} - \hat{\tau} x_{t-1} \text{ (5.21)}$$

In this way, a linear stable relation can be determined which is also known as a cointegration vector, [1-$\hat{\tau}$].

4.2.3.3 Gregory and Hansen (1996) cointegration test

The aforementioned cointegration methods assume that the cointegrating vectors remain constant over time and do not account for any structural breaks. This is a limitation of the traditional cointegration techniques, since structural breaks that result from important evens that affect the economy such as cap reforms, financial crises, natural disasters, etc. are expected to impact the long-run relations between the variables and should be accounted for. Gregory and Hansen (1996) developed a cointegration model that is based on residuals and takes into consideration structural breaks, which affect the long-run equilibrium relation.

The null hypothesis tested by Gregory and Hansen (1996) suggests that no cointegration is present in the examined variables, whereas the alternative hypothesis supports the existence of cointegration with one structural break.

The Gregory-Hansen cointegration test suggests four models as follows: model (5.22) allows a break in the intercept, model (5.23) includes a break in the intercept and trend, model (5.24) includes a break in the intercept and regime shift and model (5.25)

$$Y_t = a_0 + a_1 D_{lt} + \beta_0 X_t + u_t \text{ (5.22)}$$

where a_0 denotes the intercept before the break and $a_1$denotes the break at the intercept at the time of the structural break.

$$Y_t = a_0 + a_1 D_{lt} + \beta_0 X_t + \gamma_0 t + u_t \text{ (5.23)}$$

$$Y_t = a_0 + a_1 D_{lt} + \beta_0 X_t + \beta_l X_t D_{lt} + u_t \text{ (5.24)}$$

where β_0 denotes the cointegration parameter before the break and β_l denotes the regime shift at the time of the structural break.

$$Y_t = a_0 + a_1 D_{lt} + \beta_0 X_t + \beta_l X_t D_{lt} + \gamma_0 t + \gamma_l t D_{lt} + u_t \text{ (5.25)}$$

where γ_0 denotes the coefficient of the trend before the break, whereas γ_1 denotes the coefficient after the time of the structural break.

The Gregory and Hansen cointegration test has previously been used to examine price transmission in the Hungarian beef market (Bakucs and Fertő, 2006), the Slovak potato market (Rajcaniova and Pokrivcak, 2013), the Hungarian (Bakucs and Fertő, 2008), Polish (Bakucs *et al.*, 2012) and Russian (Kharin, 2018) milk markets, and EU corn markets (Penone *et al.*, 2022). This technique was also used to investigate financial markets (Mumba and Ziramba, 2021), and energy markets and economic growth (Bélaïd and Abderrahmani, 2013; Yavuz, 2014).

4.2.3.4 Autoregressive Distributed Lag (ARDL) cointegration technique

The majority of cointegration methods require all time series under examination to be integrated of the same order, e.g. I(1). In case where, on a bivariate model, one of the variables is I(0) and the other is I(1) and none of the variables are I(2) the Autoregressive Distributed Lag (ARDL) cointegration technique or bound cointegration testing can be performed (Pesaran and Shin, 1999; Perasan *et al.*, 2001).

The ARDL method estimates the long-run relationship through OLS and a conditional error correction model is estimated. Then, under a vector error correction model, the Granger causality test is applied. The DOLS method is based on the estimation of a long-run relationship through OLS, using lags and specifications which correct the possible bias of the researchers. The variables that are used in cointegration estimates are expressed in natural logarithms to allow for elasticities in the conduct of the results.

Apart from the fact that this technique is not limited to time series with the same order of integration, each of the variables is expressed in a standalone equation, which reduces the chances of endogeneity since there is no residual correlation (Nkoro and Uko, 2016). However, this technique cannot be applied in I(2) variables, and it also assumes a since cointegration vector between the examined variables, and thus it cannot be performed in cases where multiple cointegrating vectors exist (Perasan *et al.*, 2001).

The first step of the ARDL cointegration technique involves the estimation of the following conditional error correction model with OLS (5.26):

$$\Delta Y_t = a_0 + \sum_{t=1}^{k} a_1 \Delta Y_{t-i} + \sum_{t=1}^{k} a_2 \Delta X_{t-i} + a_2 \Delta X_{t-i} + \delta_1 Y_{t-1} + \delta_2 X_{t-1} + u_{1t} \quad (5.26)$$

Where, a_0 is the constant, δ_1 and δ_2 represent the long-run coefficients, and a_1 and a_2 the short-run coefficients.

The next step tests the null hypothesis of no cointegration through the F_{PSS} statistic, where the long-run coefficients are statistically zero, ie. H_0= δ_1=δ_2=0. The alternative hypothesis, or H_1≠δ_1≠δ_2≠0. The rejection of the null hypothesis indicates cointegration thus a long-run relation between the examined variables. Specifically, the F_{PSS} statistic is compared with the critical values proposed by Pesaran *et al.* (2001). The critical values give the lower bound which mean that the values are I(0) and the upper bound which indicate that the values are I(1). When the F_{PSS} statistic is smaller than the lower critical bound, then the null hypothesis of no cointegration cannot be rejected. However, when the F_{PSS} statistic is greater than the upper critical bound, the null hypothesis of no cointegration can be rejected. In both of these cases, there is no need for the pre-determination of the order of integration of these series. There would be a need for the order of integration of the series to be pre-determined, if the F_{PSS} statistic falls between the lower and upper critical bounds, then the results of this test are deemed unclear, and the application of an error correction model will be required to conclude to clear results regarding the existence of cointegration between the series under investigation.

If a long-run relation is confirmed, the absolute ARDL model is selected based on information criteria, such as BIC, and it is estimated as follows (5.27):

$$Y_t = a_0 + \sum_{i=1}^{p} a_1 Y_{t-i} + \sum_{i=0}^{q} a_2 X_{t-i} + \varepsilon_t \quad (5.27)$$

Where, a_0 represents the constant, and p and q the lags. This can then lead to the estimation of the long-term coefficient (γ) as demonstrated on equation (5.28).

$$\gamma = \frac{\sum_{i=0}^{q} a_2}{1- \sum_{i=1}^{p} a_1} \quad (5.28)$$

This is followed by estimating the error correction model shown below (5.29) which also considers the short-run dynamic coefficients.

$$\Delta Y_t = \beta_0 + \sum_{i=1}^{p} \beta_1 \Delta Y_{t-i} + \sum_{t=1}^{q} \beta_2 \Delta X_{t-i} + \gamma EC_{t-1} + \varepsilon_t \quad (5.29)$$

Where, EC_{t-1} shows the speed of adjustment to equilibrium, otherwise known as the error correction term, following a shock, and γ represents the term coefficient. If the coefficient is negative it indicates divergence, whereas if the coefficient is positive then this demonstrates convergence.

Following the estimation of the ARDL model, stability tests can be carried out such as the CUSUM or CUSUMQ tests. CUSUM tests use the cumulative sum or sum of squares of the differences between the values and the average, in order to determine whether the examined sequence of values is unstable, i.e., it changes in ways that are not predicted by the researcher’s model (Lee *et al.*, 2003).

The CUSUM OR CUSUMQ tests have previously been used by researchers when analysing price transmission in agricultural markets including the US beef market (Fousekis *et al.*, 2016), the dairy market in Hungary (Abdallah *et al.*, 2020) and the coffee market in Indonesia (Kamaruddin *et al.*, 2021).

4.2.3.5 Non-linear Autoregressive Distributed Lag (NARDL) cointegration technique

An extension of the ARDL model (Pesaran and Shin, 1999; Pesaran *et al.*, 2001) was proposed by Shin *et al.* (2014) since it brings some significant benefits compared to other methodologies. First of all, similar to the ARDL model (Pesaran and Shin, 1999; Pesaran *et al.*, 2001), the NARDL technique can be performed regardless of the variables having the same order of integration or not (Ahmad *et al.*, 2018). It also allows for asymmetry and cointegration to be examined under a single equation, eliminating in this way potential discrepancies in the results, and it captures both short-run and long-run asymmetry in the examined variables (Wen *et al.*, 2021). Furthermore, this technique can estimate long-run effects of a variable on another variable, which is important for policy analysis and forecasting (Shin *et al.*, 2014). However, a disadvantage of this technique is that it is considered computationally intensive and may require specialized software, thus not being widely accessible (Pal and Mitra, 2019). It also involves selecting the appropriate lag structure which can be challenging and may require subjective judgment, which can consequently lead to wrong conclusions (Dhaoui *et al.*, 2019).

Through the NARDL model, the independent variable can be split into positive and negative sums, ${x_t}^+$ and ${x_t}^-$ respectively, as shown on equation (5.30):

$$x_t = x_0 + {x_t}^+ + {x_t}^- \quad (5.30)$$

Where, ${x_t}^+$ and ${x_t}^-$ correspond to (5.31) and (5.32):

$${x_t}^+ = \sum_{j=1}^{t} \Delta {x_t}^+ = \sum_{j=1}^{t} \max(\Delta x_j, 0) \quad (5.31)$$

$${x_t}^- = \sum_{j=1}^{t} \Delta {x_t}^- = \sum_{j=1}^{t} \min(\Delta x_j, 0) \quad (5.32)$$

This leads to the following equation which gives the long-run relation (5.33):

$$y_t = \beta^+ {x_t}^+ + \beta^- {x_t}^- + u_t \quad (5.33)$$

Where, y_t denotes the independent variable, $\beta^+$and β^- represent the long-run relation between the increases and decreases of the examined variables, respectively.

The combination of the above elements, lead to the formation of model (5.34) which demonstrates the NARDL model:

$$\Delta Y_t = \mu + \rho y_{t-1} + \sum_{j=1}^{p-1} \gamma_j \Delta y_{t-j} + \Theta_j^{+} x_{t-j}^{+} + \Theta_j^{-} x_{t-j}^{-} + \sum_{j=0}^{q-1} (\pi_j^{+} \Delta x_{t-j}^{+} + \pi_j^{-} \Delta x_{t-j}^{-}) + u_t \quad (5.34)$$

Where, the long-term multipliers are represented by Θ_j^{+}= -ρ/β^{+} and Θ_j^{-}= -ρ/β^{-}.

The above model is estimated through the least squares method and then the null hypothesis of no asymmetric cointegration is tested through a modified F-statistic (F_{PSS}), whereby the values are compared with the critical values as proposed by Pesaran *et al.* (2001). This is followed by a Wald test to test the null hypothesis of long-run symmetry, $-\frac{\theta^{+}}{\rho} = \frac{\theta^{-}}{\rho}$, and null hypothesis of short-run symmetry, $\pi_j^{+} = \pi_j^{-}$. If the null hypotheses are rejected, this means that there is both long-run and short-run asymmetry in the relation under investigation. However, if none of the null hypotheses are rejected, then the model is estimated as linear ARDL.

The NARDL technique is very popular among research that relates energy markets (Li *et al.*, 2019; Dhaoui *et al.*, 2019, Çıtak *et al.*, 2021; Mujtaba *et al.*, 2022), food markets (Karantininis et al., 2011) but was also used to analyse oil prices (Pal and Mitra, 2019; Sek, 2019), financial markets and economic policy (Benlagha and Hemrit, 2022; Wen *et al.*, 2022) and food prices (Ibrahim, 2015; Fousekis *et al.*, 2016; Fousekis and Trachanas; 2016; Abdalla *et al.*, 2020; Wiseman *et al.*, 2021).

4.2.3.6 Momentum Threshold Autoregressive model (MTAR)

The traditional cointegration techniques analyse linear models. However, given the prevalence of non-linearities and asymmetries in analysing economic behaviour, there is a need to devise a cointegration approach that transcends the limitations of linear assumptions in time series samples and accommodates non-linearities and asymmetries (Shin *et al.*, 2014). The test by Engle and Granger (1987) presumes that the adjustment process towards long-term equilibrium is symmetric. Whereas Enders and Granger (1998) and Enders and Siklos (2001) have introduced the asymmetric adjustment into the cointegration tests, which allow residuals, μ_t, to follow a threshold autoregressive model (TAR) and/or a momentum autoregressive model (MTAR).

The MTAR model is expressed as follows (5.35):

$$\Delta \mu_t = I_t \rho_1 \Delta \mu_{t-1} + (1 - I_t) \rho_2 \Delta \mu_{t-1} + \sum_{t=1}^{p-1} \gamma_i \Delta \mu_{t-i} + \varepsilon_t \quad (5.35)$$

where, p denotes the lag length of $\Delta \mu_t$ which is determined through information criteria such as Schwarz or Akaike. Also I_t represents a two-value indicator function as per (5.36):

$$I_t = \begin{cases} 1\ \varepsilon\acute{\alpha}\nu\ \Delta\mu_{t-1} \geq \tau \\ 0\ ,\varepsilon\acute{\alpha}\nu\ \Delta\mu_{t-1} < \tau \end{cases} \quad (5.36)$$

where τ denotes the threshold value which is endogenously determined through Chan's (1993) method. The MTAR model involves the estimated residuals to be sorted in ascending order, whereby the 15% of the lowest and highest values are rejected. This step (equation 5.35) is repeated until one value remains which will be set as the threshold value.

The speed of adjustment is represented by ρ_1 and ρ_2 whereby each denotes the positive and negative deviations from the equilibrium at threshold value τ.

Based on the approach taken by Engle and Granger (1987), the symmetric adjustment is presented as ρ_1=ρ_2, whereas the asymmetric adjustment as per Endres and Granger (1998) and Engers and Siklos (2001) exists when ρ_1<0, ρ_2<0 και $\rho_1 \neq \rho_2$. Also, to ensure that the estimated residuals, μ_t, are stationary in model (5.35), then 2<(ρ1,ρ2)<0 should apply for each value at threshold value τ.

The test provides the F-joint (Phi) value which is used to test the null hypothesis of no cointegration ($\rho_1 = \rho_2 = 0$) and the asymptotic critical values as suggested by Enders and Siklos (2001). When Phi value exceeds critical value, then the null hypothesis of no cointegration can be rejected which means that the examined variables are cointegrated in the long run. Once a long-run relationship is established, the null hypothesis of symmetry can be tested through the F-equal value. When F-equal value exceeds the critical value, then the null hypothesis of symmetry can be rejected, indicating the presence of asymmetry. If both null hypotheses are rejected, implying asymmetric cointegration, then the following asymmetric error correction model can be applied (5.36):

$$\Delta Y_t = a_0 + \sum_{i=1}^{p} a_1 \Delta Y_{t-i} + \sum_{i=1}^{p} \beta_2 \Delta X_{t-i} + \delta_1 I_t \Delta_{\mu-1} + \delta_2 (1 - I_t) \Delta\mu_{t-1} + \varepsilon_t \quad (5.36)$$

where p denotes the lag length and I the indicator function. Also, the residuals are represented by μ_t, and δ_1 and δ_2 correspond to the adjustment coefficient to positive and negative deviations, respectively, from the threshold value τ. The error correction model also allows for the Granger (1969) causality test to determine short-term causation between the variables.

The MTAR model has previously been utilised in studies examining volatility in financial and monetary policy markets (Zapf and Payne, 2009; Apergis *et al.*, 2012) as well as oil and stock prices (Chen *et al.*, 2013; Rafailidis and Katrakilidis, 2014).

4.2.3.7 Diks and Panchenko (2006) causality test

To examine price relations, it is considered crucial to determine the causal relationship to understand the direction of causation; this indicates that a change in one variable can cause a change in the other variable. In this sense, past values of one series can be used to forecast changes and the behaviour of another. In price transmission studies, it is of paramount importance to identify the central market, i.e., the market where the shock initially arises and engenders a reaction in the other market. This allows to gain insights into the mechanisms that underlie price movements and their propagation across markets. Some researchers designate the central market based on particular market characteristics, i.e., being the largest examined market in terms of volume as suggested by Goodwin and Piggott (2001), who examined corn and soybean markets in North Carolina and Serra *et al.* (2006b) for poultry in the EU. The present study, however, followed the approach that was used by other researchers (Tiffing and Dawson, 2000; Abdulai, 2002; Fousekis and Trachanas, 2016) which is utilising causality tests. As such, the non-linear causality test proposed by Diks and Panchenko (2006) has been selected because it reduces bias and the possibility of rejecting the null hypothesis, since their proposed causality test is based on asymptotic theory meaning that they allow the bandwidth to be chosen based on the sample size.

According to Baek and Brock (1992), performing a linear causality test such as the one introduced by Granger (1969) can generate weaker results compared to non-linear tests. This is because any non-linearities that may be present in the examined relationships are ignored which may lead to false conclusions. Therefore, it is beneficial to take a non-linear approach to examine causal relationships since non-linear models can detect non-linearities price series. A similar non-linear causality approach has been suggested by Hiemstra and Jones (1994). Even though it accounts for non-linearities in the examination of causal relationships, it has been criticized by Dics and Panchenko (2006) that it can over-reject the null hypothesis and size distortion (Kurgul and Lach, 2010).

Diks and Panchenko (2006) suggest that the revised null hypothesis implies the relation (5.37):

$$q \equiv E\left[f_{X,Y,Z}(X,Y,Z)f_Y(Y) - f_{X,Y}(X,Y)f_{Y,Z}(Y,Z)\right] = 0 \quad (5.37)$$

which assumes that $\hat{f}_W(W_i)$ is the local density estimator of the d_w-variate vector W in W_i which is defined by relations (5.38) and (5.39):

$$\hat{f}_W(W_i) = (2\varepsilon_n)^{-d_W}(n-1)^{-1}\sum_{j,j\neq i} I_{ij}^W \quad (5.38)$$

Where,

$$I_{ij}^{W} = I\left(\left|W_i - W_j\right| < \varepsilon_n\right) \text{ (5.39)}$$

I(.) is an indicator function, ε_n represents the bandwidth and n the sample size. The test statistic is presented in equation (5.40):

$$T_n(\varepsilon_n) = \frac{n-1}{n(n-2)} \sum_i \left(\hat{f}_{X,Y,Z}(X_i, X_i, Y_i) \hat{f}_Y(Y_i) - \hat{f}_{X,Y}(X_i, Y_i) \hat{f}_{Y,Z}(Y_i, Z_i) \right) \text{ (5.40)}$$

Diks and Panchenko (2006) proved that when $l_X = l_Y = 1$ and $\varepsilon_n = Cn^{-\beta}$ (C>0, 1/4<β<1/3), then the statistical importance satisfies the relation (5.41):

$$\sqrt{n} \frac{(T_n(\varepsilon_n) - q)}{S_n} \xrightarrow{D} N(0,1) \text{ (5.41)}$$

where $\xrightarrow{D}$ implies convergence in distribution and S_n denotes an estimator of the asymptotic variance of $T_n(\cdot)$ (Diks and Panchenko, 2006).

The non-linear causality test of Diks and Panchenko (2006; 2013) has been widely applied to examine causal relations in different fields such as exchange rates and stock prices, and trade and economic growth (Aworinde, 2013; Karagianni *et al.*, 2012; 2019; Ajmi *et al.*, 2015; Choudhry *et al.*, 2015; De Vita and Trachanas, 2016; Kollias et. al., 2017; Makatjane *et al.*, 2017). This test was also employed to analyse causal relations in agricultural commodity markets (Nazlioglu, 2011; De Vita and Trachanas, 2016; Shahbaz *et al.*, 2017; Bodhanwala *et al.*, 2018; Fiszeder and Orzeszko, 2018), however no study has employed this test in the context of investigating causation between the principal markets of a particular agricultural commodity. Nevertheless, this technique is considered superior to other, as it reduces bias and minimizes the chance of rejection of the null hypothesis of no granger causality between the price pairs.

4.2.3.8 Hacker and Hatemi-J (2010) bootstrap causality test

Another causality test that is performed in this study is the bootstrap causality test by Hacker and Hatemi (2010). Hacker and Hatemi-J (2006; 2010; 2012) and Hatemi-J (2012) developed the leverage bootstrap causality test which determines the optimal lag length endogenously in the VAR model.

Through the bootstrap process, the original dataset undergoes multiple resampling to estimate the distribution of the causal effect of variable x to variable y.

While the traditional Granger causality test is used on time series data assuming normal distribution, Hacker and Hatemi-J (2010) used bootstrapping on the statistic produced by the Granger causality test and can be applied to data that is not normally distributed. Therefore, the bootstrap causality test proposed by Hacker and Hatemi-J (2010) offers an alternative causality test for data that are not normally distributed providing greater flexibility. Another advantage is that it is easy to apply and can also be applied with non-stationary data.

Researchers examining price transmission in agricultural commodity markets has utilised this model to analyse causal relations in international skim milk powder markets (Fousekis and Trachanas, 2016), oil prices and exchange rates in Romania (Taşar, 2017) and US pork markets (Panagiotou, 2021).

4.3 Data

The data employed in the empirical analysis of this study refer to monthly prices at wholesale level of virgin (VOO) and extra virgin olive oil (EVOO) expressed in Euros per 100 Kilogram. The price data represent national prices in the three major EU olive oil markets; specifically Spain (ES), Italy (IT) and Greece (GR). They were obtained from the European Commission's Agricultural and Rural Development Directorate and span from January 2000 to April 2022. The number of observations for each examined country is 536 observations and they total to 1608 observations. It is worth noting that, Portugal is not included in the present sample due to gaps in price data throughout the examined period, even though it has increased its olive oil production substantially.

All prices have been converted to natural logarithms to reduce the skewness of the original data. Summary and descriptive statistics on olive oil prices and price logarithms are presented in later sub-sections of this chapter (VOO and EVOO sections) and are expressed as follows: ES_V, IT_V, GR_V represent wholesale virgin olive oil prices in Spain, Italy and Greece, respectively; ES_EV, IT_EV, GR_EV represent wholesale extra virgin olive oil prices in Spain, Italy and Greece, respectively; L_ES_V, L_IT_V, L_GR_V represent price logs of virgin olive oil in Spain, Italy and Greece, respectively; whereas L_ES_EV, L_IT_EV, L_GR_EV represent price series for wholesale extra virgin olive oil prices in Spain, Italy and Greece respectively, expressed in natural logarithms.

4.4 An empirical examination of price linkages in EU olive oil markets: The case of Virgin olive oil

Price linkages in olive oil markets in Spain, Italy and Greece in relation to the virgin olive oil quality have been examined through the following econometric tests: the ADF (Dickey and Fuller, 1981) and PP (Phillips and Perron, 1988) unit root tests, the Zivot-Andrews (1992) and Perron (1989) unit root tests with one structural break, and the Lee and Strazicich (2004) unit root test with two structural breaks. This is followed by the Johansen (1988) cointegration test, a Vector Error Correction model, the Diks and Panchenko (2006) non-parametric Granger Causality test and the Gregory and Hansen (1996) cointegration test with one structural break as well as the Momentum Threshold Autoregressive (MTAR) test (Engers and Siklos, 2001).

4.4.1 Descriptive Statistics

Figure 28 exhibits the wholesale prices of virgin olive oil in Spain (ES), Italy (IT), and Greece (GR) for the period 01/2000-04/2022 expressed in natural logarithms. Prices in all three markets appear to comove with GR being characterised by relatively higher volatility in prices at times. Prices in ES and IT seem to be a lot closer and regularly overlap at the highest levels, while at the lower levels IT reaches lower prices than ES. It is deduced the GR generally follows similar trends to the other two markets with comparably lower peaks and troughs.

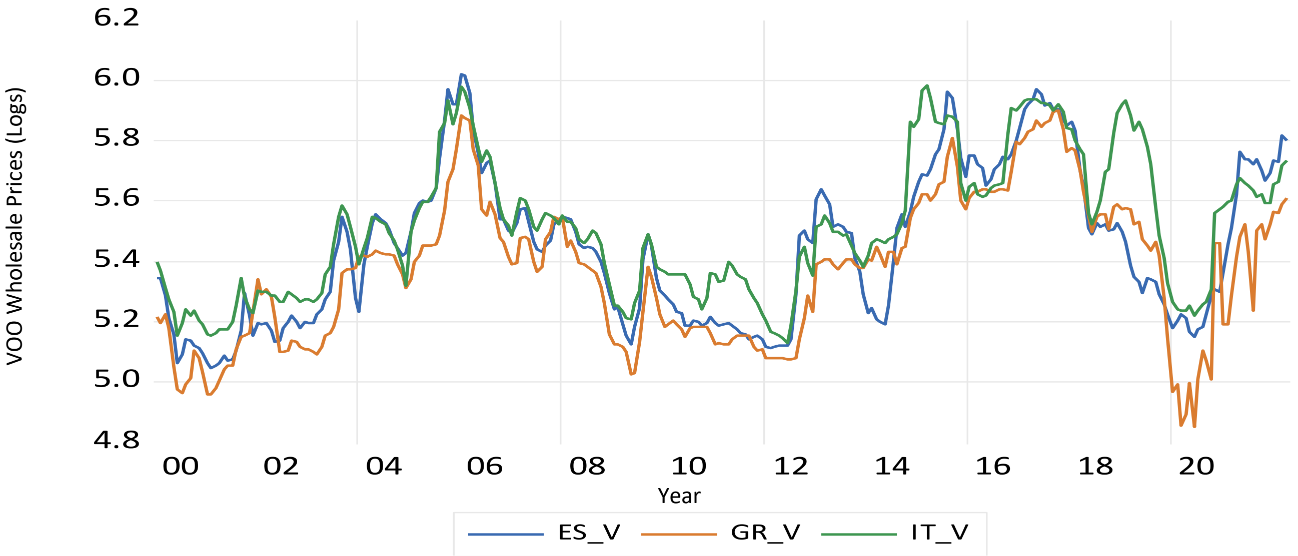


Figure 28. Natural logarithms of Virgin olive oil wholesale prices - ES, IT, GR

According to *Table 6*, IT has the highest mean ($\bar{x}$ = 251.06) followed by ES ($\bar{x}$ = 239.39) and GR ($\bar{x}$ = 221.16). This may be attributed to the tendency of prices being higher in a market that has a product deficit (i.e. IT) compared to surplus markets (i.e. ES and GR). Even though IT noted the highest mean, the maximum price observation within the examined sample was recorded by ES (€410.92/100 kgs). The maximum prices for IT and GR were €396.83/100 kgs and €364.97/100 kgs, respectively. Conversely, IT noted the highest minimum price (€168.89/100 kgs) resulting in the narrowest price range out of the three examined markets, while ES and GR marked €155.48/100 kgs and €128.00/100 kgs, respectively. The dispersion of prices in all examined markets is low with standard deviation values of ES=0.25, IT=0.23 and GR=0.24 (SD<1), while data appear to be moderately positive skewed. Furthermore, the distribution is characterised as platykurtic (kurtosis<3) and the null hypothesis of normality can be rejected in all examined cases (p<0.05).

Table 6. Descriptive statistic for Virgin olive oil prices in raw form and natural logarithms

	ES_V	L_ES_V	IT_V	L_IT_V	GR_V	L_GR_V
Mean	239.3930	5.445682	254.0612	5.510793	221.1620	5.369894
Maximum	410.9242	6.018409	396.8276	5.983502	364.9677	5.899809
Minimum	155.4797	5.046515	168.8929	5.129265	128.0000	4.852030
Std. Dev.	62.94953	0.251912	60.57978	0.229091	54.25662	0.240176
Skewness	0.747451	0.369727	0.704960	0.376471	0.628695	0.161298
Kurtosis	2.672405	2.079970	2.446226	2.113085	2.822165	2.268779
Jarque-Bera	26.15288	15.55793	25.62233	15.11454	18.00797	7.132733
Probability	0.000002	0.000418	0.000003	0.000522	0.000123	0.028258
Observations	268	268	268	268	268	268

4.4.2 Unit Root Tests

The first step in the empirical analysis is to test and establish the level of integration of the variables through unit root tests or tests for stationarity. In particular, the univariate ADF unit root test by Dickey and Fuller (1981) is applied to the wholesale price series of olive oil (EVOO and VOO) for ES (Spain), IT (Italy) and GR (Greece). This is followed by the PP unit root test by Phillips-Perron (1988) which is also performed to strengthen the validity of the results. The null hypotheses of both tests suggest the existence of a unit root between the examined series, whereas the alternative hypotheses support that the series do not have a unit root.

Table 8 presents the results from the ADF and PP unit root tests in the levels and first differences for VOO. The first part of the table presents the model including a constant, and in the second part the model includes a constant and a trend. The critical values based on MacKinnon (1996) for significance levels 1% and 5% are also provided under the table and the optimal lag length was selected based on the Schwarz Info Criterion for the ADF test and the Newey-West Bandwidth method with Bartlett kernel for the PP test.

Based on the results from *Table 7*, the ES, IT and GR price series are non-stationary in the levels with intercept, whereas when they are expressed in the first differences all price series are stationary at 1% significance level and are therefore characterised as integrated of order 1, I(1). This is also the case when the model includes an intercept and a trend. Similar results are reached when performing the PP unit root test in both models, including a constant, and a constant and trend.

Table 7. ADF (1981) and PP (1988) unit root tests

Intercept									
Variable	**ADF**		**PP**		**Variable**	**ADF**		**PP**	
	t-value	*k*	Adj. t-Stat	*k*		t-value	*k*	Adj. t-Stat	*k*
ES	-2.74	1	-2.07	3	ΔES	-9.92***	1	-9.422***	4
IT	-2.72	1	-2.58	6	ΔIT	-11.57***	0	-11.56***	2
GR	-2.11	0	-2.33	5	ΔGR	-14.13***	0	-14.05***	3
Intercept and Trend									
Variable	**ADF**		**PP**		**Variable**	**ADF**		**PP**	
	t-value	*k*	Adj. t-Stat	*k*		t-value	*k*	Adj. t-Stat	*k*
ES	-3.05	1	-2.37	3	ΔES	-9.90***	1	-9.409 ***	4
IT	-3.09	1	-2.97	6	ΔIT	-11.55***	0	-11.54 ***	2
GR	-2.70	1	-2.57	5	ΔGR	-14.10***	0	-14.02 ***	3

Notes:
Δ denotes first differences.
ADF and PP denote the Augmented Dickey-Fuller unit root test and the Phillips-Perron unit root test, respectively.
The tests have been performed using Eviews software, V12.
k denotes the optimal lag structure of the ADF test that was selected based on the Schwarz Information Criterion, while the number of lags for the PP test was determined based on Newey-West Bandwidth method with Bartlett kernel.
The critical values for the ADF and PP unit root tests in the intercept are -3.45 and -2.87 for significance level 1 and 5%, respectively, while the critical values in both the intercept and trend are -3.99 and -3.43 for significance level 1 and 5%, respectively (MacKinnon, 1996).
*** and ** denote the rejection of the null hypothesis of the series having a unit root at significance level 1 and 5%, respectively.

4.4.3 Unit Root Tests with Structural Breaks

Considering that the power of the ADF and PP tests is significantly reduced when there is a structural break in the examined series (Perron, 1989), the Zivot-Andrews (1992) and the Perron (1997) unit root tests with one structural break are also performed. This will allow to address any possible misleading conclusions that could arise from tests that fail to account for structural breaks. *Table 8* presents the results from the Zivot-Andrews (1992) and the Perron (1997) unit root tests. In addition, the critical values for both tests are presented for the models with intercept and the models with intercept and trend for significance levels 1% and 5%. The optimal lag length *k* has been determined based on the Akaike (AIC) and Schwarz Information Criteria, for the Zivot-Andrews and PP tests, respectively. The results from both tests further confirm that the series ES, IT and GR are stationary with one structural break at 1% significance level, when the tests are performed with the first differences and thus are considered integrated of order 1, I(1). The structural breaks based on the Zivot-Andrews test are identified in 2008 and 2006 for Spain, 2014 and 2006 for Italy, and 2018, 2006 and 2017 for Greece. The dates of the structural breaks based on the Perron test are identified in 2008 and 2006 for Spain, 2013, 2014 and 2006 for Italy, and 2018 and 2006 for Greece.

Table 8. Zivot-Andrews (1992) and the Perron (1997) unit root tests with one structural break

Intercept – Levels							**Intercept – First Difference**						
Variable	**Zivot-Andrews**			**Perron**			**Variable**	**Zivot-Andrews**			**Perron**		
	T_B	k	t-statistic	T_B	K	t-statistic		T_B	k	t-statistic	T_B	k	t-statistic
ES	2008M04	2	-2.99	2008M03	1	-3.47	ΔES	2006M02	4	-6.68***	2006M01	4	-6.85***
IT	2014M01	1	-3.48	2013M12	1	-3.48	ΔIT	2006M02	0	-11.71***	2014M11	0	-12.46***
GR	2018M03	3	-3.01	2018M01	2	-2.78	ΔGR	2006M04	2	-9.07***	2006M01	0	-14.37***
Intercept and Trend – Levels							**Intercept and Trend – First Difference**						
Variable	**Zivot-Andrews**			**Perron**			**Variable**	**Zivot-Andrews**			**Perron**		
	T_B	k	t-statistic	T_B	K	t-statistic		T_B	k	t-statistic	T_B	k	t-statistic
ES	2006M08	2	-3.47	2006M01	1	-4.15	ΔES	2006M02	4	-6.74***	2006M01	4	-6.84***
IT	2006M08	1	-3.95	2006M07	1	-3.95	ΔIT	2006M02	0	-11.80***	2014M11	0	-12.43***
GR	2006M04	3	-3.28	2006M03	2	-3.10	ΔGR	2017M11	2	-9.27***	2006M01	0	-14.42***

Notes:
Δ denotes first differences.
T_B denotes the time of the structural break.
k denotes the optimal lag structure of the Zivot-Andrews test that was selected based on the Akaike (AIC) Information Criterion, while the number of lags for the Perron test was determined based on the Schwarz Information Criterion.
The tests have been performed using Eviews software, V12.
The critical values for the Zivot-Andrews unit root test with one structural break in the intercept are -5.34 and -4.93 for significance level 1 and 5%, respectively, while the critical values in both the intercept and trend are -5.57 and -5.08 for significance level 1 and 5%, respectively.
The critical values for the Perron unit root test with one structural break in the intercept are -5.92 and -5.23 for significance level 1 and 5%, respectively, while the critical values in both the intercept and trend are -6.32 and -5.59 for significance level 1 and 5%, respectively.
*** and ** denote the rejection of the null hypothesis of the series having a unit root with a structural break at significance level 1 and 5%, respectively.

Moreover, the unit root test proposed by Lee and Strazicich (2003) is further employed accounting for two structural breaks in the examined series. The test is performed in two models; model A which includes the breaks in the intercept and Model C which includes the breaks with trend. The estimated t-statistics are compared with the critical values provided by Lee and Strazicich (2003) to examine the null hypothesis of the presence of a unit root in the examined series with two structural breaks. The results are shown in *Table 9* and indicate that the series ES and GR are stationary with two structural breaks at 1% significance level when the tests are performed in the first differences (integrated of order 1, I(1)). However, series IT is stationary at the levels with two structural breaks at 5% significance level. The structural breaks based on the Lee-Strazicich (2003) test are identified in 2003, 2005, 2009 and 2014 for Spain, 2004, 2005 and 2006 for Italy, and 2006, 2008, 2009 and 2012 for Greece.

Table 9. Lee-Strazicich (2003) unit root test with two structural breaks

Model A – Levels					**Model A – First Difference**				
Variable	T_{B1}	T_{B2}	**k**	**T-Statistic**	**Variable**	T_{B1}	T_{B2}	**k**	**T-Statistic**
ES	2003M06	2006M09	5	-3.234	ΔES	2005M08	2017M07	4	-6.671***
IT	2004M12	2014M10	5	-4.121**	ΔIT	2005M11	2008M03	1	-8.027***
GR	2008M11	2018M02	8	-2.815	ΔGR	2006M08	2017M04	7	-5.996***
Model C – Levels					**Model C – First Difference**				
Variable	T_{B1}	T_{B2}	**k**	**T-Statistic**	**Variable**	T_{B1}	T_{B2}	**k**	**T-Statistic**
ES	2009M10	2017M12	5	-3.747	ΔES	2014M03	2018M03	1	-10.573***
IT	2006M06	2014M10	5	-4.510	ΔIT	2005M11	2012M12	1	-9.702***
GR	2009M10	2017M09	8	-3.748	ΔGR	2012M11	2016M11	7	-8.110***

Notes:
Δ denotes first differences.
T_{B1} and T_{B2} denote the time of the structural breaks.
k denotes the optimal lag structure.
The optimal lag structure for the Lee and Strazicich (2003) test was selected following a general to specific procedure.
The tests have been performed using GAUSS code provided by Lee Strazicich (2003).
The critical values are provided by Lee and Strazicich (2003).
*** and ** denote the rejection of the null hypothesis of the series having a unit root with two structural breaks at significance level 1 and 5%, respectively.

4.4.4 Cointegration and Causality Analysis

Following the examination of stationarity in the examined series both with and without structural breaks, the next steps involve establishing the long-run relationships and determining the direction of causality between the variables.

Based on Nazlioglu (2011), who examined non-linear causal relationships between world oil and agricultural commodity prices (corn, soybeans, and wheat), a 3-step approach was applied in this study. The process initially involves the application of the Johansen (1988) cointegration test, Vector Error Correction model (VECM) and Diks and Panchenko (2006) causality test.

4.4.4.1 Johansen Cointegration Technique

The first step includes the estimation of a multivariate cointegration test can and since all the examined price series are integrated of order 1, the ML (Maximum Likelihood) cointegration test proposed by Johansen (1988) and Johansen and Juselius (1990) has been selected. This step will determine the number of cointegrating vectors and is performed pairwise (GR-ES, GR-IT, IT-ES) to indicate the number of long-run relationships that exist in the samples.

According to the results shown in *Table 10*, the first null hypothesis of no cointegrating vectors (r=0) can be rejected for all three pairs at 5% significance level. The trace statistics for GR-ES, GR-IT and IT-ES are 27.495, 37.990 and 27.775, respectively, which exceed the critical values, suggesting the existence of cointegration between the examined variables. These results are also confirmed by the max-eigen statistics for GR-ES, GR-IT and IT-ES which are 20.739, 31.640 and 21.353, respectively, being greater than the additional critical values. Since the first null hypothesis of no cointegration has been rejected in all three cases, the second null hypothesis of at most 1 cointegrating vector ($r \leq 1$) between the examined pairs is tested. Based on the results presented in *Table 11*, the trace and max-eigen statistics for GR-ES, GR-IT and IT-ES are 6.756, 6.350 and 6.421, respectively. Because these values are smaller than the critical values, then the null hypothesis of at most 1 cointegrating vector cannot be rejected, indicating the existence of one cointegrating vector between each examined pair. These results are also confirmed by the p-values.

Table 10. Johansen Cointegration Test Results

Pair		Null Hypothesis	Trace Statistic	Max-Eigen Statistic
EL	ES	r=0	27.495 (0.031) **	20.739 (0.031) **
		r≤1	6.756 (0.370)	6.756 (0.370)
EL	IT	r=0	37.990 (0.001) **	31.640 (0.000) **
		r≤1	6.350 (0.417)	6.350 (0.417)
IT	ES	r=0	27.775 (0.028) **	21.353 (0.025) **
		r≤1	6.421 (0.408)	6.421 (0.408)

Notes:
r denotes the number of cointegrating vectors under the null hypothesis.
The critical values for both the Trace Test are 25.872 for null hypothesis r=0 and 12.517 for null hypothesis r≤1, whereas the critical values for the MaximumEigen Value Test are 19.387 for null hypothesis r=0 and 12.517 for null hypothesis r≤1.
The tests have been performed using Eviews software, V12.
In () the p values are provided as suggested by MacKinnon-Haug-Michelis (1999).
** denotes the rejection of the null hypothesis of no cointegrating vectors at significance level 5%.

4.4.4.2 Vector Error Correction Model (VECM)

The second step employs a Vector Error Correction Model (VECM) to filter the data for each pair and provide the residuals in preparation of the Diks and Panchenko (2006) causality test.

The VECM is performed with intercept and trend and the optimal number of lags is determined based on the Schwarz (SC) information criterion. Once the residuals are produced, a VEC Residual Serial Correlation LM Test is applied to ensure that they are not affected by serial correlation. These are then extracted and used to perform the non-parametric Granger Causality test based on Diks and Panchenko (2006). This practice contradicts the one followed by Nazlioglu (2011) that produced VAR residuals for the DP test. According to De Vita and Trachanas (2016), the use of VAR or VECM residuals depends on the order of integration of the examined series. Specifically, VAR residuals should be used if the series are I(0), or I(1) but not cointegrated, and VECM residuals should be used when the examined series are I(1) and cointegrated.

4.4.4.3 Diks and Panchenko (2006) causality test

To examine causality, the Diks and Panchenko (2006) causality test is applied in two ways. Initially, the first differences which have been confirmed as the stationary series are used, to identify non-linear interrelations. Then, the test is re-applied on the estimated residual series of the VEC model derived from the process described in 5.4.4.2 to ensure that no non-linearities exist in the sample. In both cases, the bandwidth value (ε) in the DP test is set in accordance with Diks and Panchenko (2006) who tabulated the corresponding bandwidth (ε=1.50) depending on the time series length (n>200).

Table 11 presents the results from the Diks and Panchenko causality test performed on the first differences. The results indicate that ES causes both GR and IT, IT causes GR but not ES, and GR does not cause ES or IT.

Table 11. Diks and Panchenko Causality Test on First Differences

K	Greece & Spain		Greece & Italy		Italy & Spain	
LX = LY	EL≠ >ES	ES ≠ > EL	EL ≠> IT	IT ≠> EL	IT ≠> ES	ES ≠>IT
1	0.002 (0.499)	2.603*** (0.004)	0.564 (0.286)	2.035** (0.020)	0.672 (0.250)	1.335* (0.090)
2	0.280 (0.389)	2.826*** (0.002)	-0.371 (0.644)	2.166** (0.015)	0.892 (0.186)	1.206 (0.113)
3	0.591 (0.277)	2.834*** (0.002)	-0.457 (0.675)	1.826** (0.033)	0.948 (0.171)	1.509* (0.065)
4	0.514 (0.303)	2.651*** (0.004)	-0.307 (0.620)	2.090** (0.018)	1.041 (0.148)	1.887** (0.029)
5	-0.486 (0.686)	2.264** (0.011)	-0.706 (0.759)	2.193** (0.014)	1.094 (0.136)	1.302* (0.096)

Notes
***, ** & * denote the rejection of the null hypothesis that LX does not cause LY at significance levels 1%, 5% and 10%, respectively.
In brackets the p-values are presented.
The tests have been performed using code provided by Diks and Panchenko (2006).
Symbol ≠ > means that X does not cause Y.
Symbol k denotes that optimal lag length.

These results are also confirmed when performing the DP test on the VEC residuals as shown on *Table 12*.

Table 12. Diks and Panchenko Causality Test on VEC Residuals

K	Greece & Spain		Greece & Italy		Italy & Spain	
LX = LY	EL≠ >ES	ES ≠ > EL	EL ≠> IT	IT ≠> EL	IT ≠> ES	ES ≠>IT
1	-0.171 (0.568)	0.866 (0.193)	0.228 (0.409)	1.305* (0.096)	0.293 (0.384)	-0.605 (0.727)
2	-1.080 (0.859)	1.763** (0.038)	-0.403 (0.656)	1.933** (0.026)	1.321* (0.093)	1.663** (0.048)
3	-0.312 (0.622)	2.128** (0.016)	-0.078 (0.531)	2.030** (0.021)	0.769 (0.220)	1.718** (0.042)
4	0.012 (0.495)	2.683*** (0.003)	-0.176 (0.570)	1.965** (0.024)	0.817 (0.207)	1.866** (0.031)
5	-0.452 (0.674)	2.636*** (0.004)	-0.761 (0.776)	1.898** (0.028)	0.804 (0.210)	1.525* (0.063)

Notes
***, ** & * denote the rejection of the null hypothesis that LX does not cause LY at significance levels 1%, 5% and 10%, respectively.
In brackets the p-values are presented.
The tests have been performed using code provided by Diks and Panchenko (2006).
Symbol ≠ > means that X does not cause Y.
Symbol k denotes that optimal lag length.

4.4.4.4 Engle and Granger cointegration test

The Diks and Panchenko (2006) causality test performed in the previous section has determined the direction of causality between the examined pairs. Thus, a further cointegration test to examine the long-run relationship between the variables is applied using the Engle-Granger bivariate cointegration model. The first step of the Engle-Granger test involves an OLS autoregression which will provide the residuals that need to be stationary at the levels to indicate the existence of cointegration. This is then followed by the second step which performs a standard unit root test using the OLS residuals. *Table 13* exhibits the results from the OLS which forms the first step of the Engle-Granger cointegration and *Table 14* presents the results from the second step of the test which examines stationarity in the residuals.

Table 13. Engle-Granger cointegration test - Step one OLS

Variables			
Dependent	**Independent**	**Coefficient (C1)**	**Constant (C0)**
GR	ES	0.862 (34.562) ***	0.674 (4.959) ***
GR	IT	0.968 (39.419) ***	0.031 (0.231) ***
IT	ES	0.810 (32.071) ***	1.096 (7.957) ***

Notes:
The optimal lag structure was selected based on the Schwarz Information Criterion.
The tests have been performed using Eviews software, V12.
In () the t-statistics are presented.
*** denotes the rejection of the null hypothesis at 1% significance level.

Table 14. Engle-Granger cointegration test - Step two ADF and PP unit root tests on OLS residuals

Variables		T-statistic	
Dependent	**Independent**	**ADF**	**PP**
GR	ES	-4.705***	-5.160***
GR	IT	-5.419***	-5.419***
IT	ES	-4.294***	-4.143***

Notes:
The optimal lag structure was selected based on the Schwarz Information Criterion.
The tests have been performed using Eviews software, V12.
The critical values are provided by MacKinnon (1996).
*** denotes the rejection of the null hypothesis at 1% significance level.

The elasticities of the long-term coefficients demonstrate that there is positive and statistically significant relationship between all examined pairs (t-statistic > ± 1.64). Therefore, changes in the prices of virgin olive oil (VOO) may be a result of a shock in consumer demand. Specifically, for the pair Greece-Spain (with Spain being the causal market), 1% increase in the prices for VOO in Spain leads to 0.86% increase in price of VOO in Greece. In relation to the pair Greece-Italy (with Italy being the causal market), 1% increase in Italian VOO causes a 0.96% increase in Greek VOO. Finally, for pair Italy-Spain (with Spain being the causal market), 1% increase in the prices of VOO in Spain causes a 0.81% increase in the prices of VOO in Italy.

While all three pairs seem to exhibit very strong long-term cointegration relations, the pair Greece-Italy appears to have a stronger relationship, compared to shocks from Italy in the Spanish VOO market prices. This may be explained by the fact that 77.5% of Greek olive oil exports have Italy as their destination; thus, establishing this relation (European Commission, 2021c).

4.4.4.5 Gregory and Hansen cointegration technique with structural breaks

To ensure the validity of the findings pertaining to long-term cointegration relationships between the variables, a cointegration method that takes into consideration structural breaks is implemented, as neglecting the presence of such breaks in a relationship may result in spurious conclusions.

The cointegration technique applied is the Gregory-Hansen (Gregory and Hansen, 1996) model with one structural break. This model does not require any preliminary information to identify the time of the structural break, as this is determined endogenously from the data.

Table 15 presents the results from the Gregory-Hansen cointegration tests through the ADF, Z_a and Z_t statistics. All statistics for the pairs ES-GR and IT-GR reach similar conclusions at 1% and 5% significance levels, indicating the presence of a long-run cointegration relation with one structural break between these pairs. For the pair ES-IT, while the ADF statistic confirms the same conclusion at 1% significance level in model C and model C/S and at 5% significance level, the Z_a and Z_t statistics confirm that the pair is cointegrated in the long-run with one structural break only in model C/S at 1% significance level.

In terms of the time of the structural breaks, the majority of these are identified between 2013 and 2018 for all pairs, while for ES-IT some structural breaks are identified during late 2003 – early 2004.

Table 15. Gregory Hansen cointegration test results with one structural break

	Spain - Greece			Italy - Greece			Spain - Italy		
	Statistic	T_B	**k**	**Statistic**	T_B	**k**	**Statistic**	T_B	**k**
ADF test									
Model C	-5.611***	2013M06	1	-5.038**	2018M10	8	-5.353***	2014M01	5
Model C/T	-5.872***	2013M06	1	-6.036***	2018M11	7	-5.128**	2014M01	5
Model C/S	-5.679***	2018M11	1	-5.988***	2018M09	7	-12.516***	2004M03	1
Z_a **test**									
Model C	-51.400***	2013M08	1	-77.981***	2018M10	8	-37.440*	2014M06	5
Model C/T	-55.113**	2013M08	1	-79.852***	2018M10	7	-32.341	2014M05	5
Model C/S	-51.417**	2013M08	1	-76.619***	2018M10	7	-178.905***	2003M09	1
Z_t **test**									
Model C	-5.283***	2013M08	1	-6.676***	2018M10	8	-4.381*	2014M06	5
Model C/T	-5.517***	2013M08	1	-6.759***	2018M10	7	-4.070	2014M05	5
Model C/S	-5.287***	2018M11	1	-6.610***	2014M09	7	-11.272***	2003M09	1

Notes:
T_B denotes the time of the structural break.
k denotes the optimal lag structure of the Zivot-Andrews test that was selected based on the Akaike (AIC) Information Criterion, while the number of lags for the Perron test was determined based on the Schwarz Information Criterion.
The tests have been performed using code provided by Gregory and Hansen (1996) on Eviews software, V12.
The critical values for the Zivot-Andrews unit root test with one structural break in the intercept are -5.34 and -4.93 for significance level 1 and 5%, respectively, while the critical values in both the intercept and trend are -5.57 and -5.08 for significance level 1 and 5%, respectively.
The critical values for the Perron unit root test with one structural break in the intercept are -5.92 and -5.23 for significance level 1 and 5%, respectively, while the critical values in both the intercept and trend are -6.32 and -5.59 for significance level 1 and 5%, respectively.
*** and ** denote the rejection of the null hypothesis of the series having a unit root with a structural break at significance level 1 and 5%, respectively.

4.4.4.6 Momentum Threshold Autoregressive (MTAR) test

As a last step, the pattern of the price transmission relations is examined. Thus, the presence of asymmetries between the price pairs is explored through the MTAR model as suggested by Enders and Siklos (2001).

Table 17 presents the results from the MTAR test where the threshold value (T) is estimated endogenously using Chan's (1993) method and gives the *ρ1* and *ρ2* parameters that represent the asymmetric adjustment to positive and negative deviations from the equilibrium, respectively. The τ value reflects the threshold value of transportation costs (Ankahamah-Yeboah, 2013) and its determination allows for the impact of transportation costs to also be considered in the spatial price relationship (Goodwin and Piggott, 2001). The null hypothesis $\rho 1=\rho 2=0$ suggest no cointegration between the examined variables, whereas the null hypothesis $\rho 1=\rho 2$ suggests the presence of symmetry**.**

The results on *Table 16* indicate that the null hypothesis of no cointegration can be rejected for all the examined pairs at 1% significance level, with the F-statistic for GR-ES, GR-IT and IT-ES being 16.060, 14.469 and 16.122, respectively. On the contrary, the null hypothesis for symmetric adjustment cannot be rejected only for Greece and Italy at 1% significance level, whereas it can be rejected in the case of Spain. In addition, parameters ρ1 and ρ2 are negative and statistically significant at 1% for all pairs apart from pair GR-ES, where the parameter of positive deviations is significant at 5% significance level.

Furthermore, for all pairs, parameters ρ1 and ρ2 show convergence with the adjustment being greater to negative deviations (ρ2) than positive deviations (ρ1). Specifically, for the pair GR-ES, with Spain forcing, the adjustment to positive deviations (ρ1) is around 12 months compared to approximately 2 months to negative deviations (ρ2) from equilibrium τ=-0.035. In case of a positive shock, approximately 8.1% of the deviation is covered, whereas in the case of a negative shock this percentage reaches approximately 35.9% per month. Therefore, approximately 92% and 64% from the positive and negative deviations respectively, persist in the following months. Similarly, for the pair IT-ES, with Spain forcing, the adjustment to positive deviations (ρ1) is approximately 16 months compared to around 3 months to negative deviations (ρ2) from equilibrium τ=-0.029. This means that approximately 6.1% and 29.6% of positive and negative deviations, respectively, from equilibrium, are corrected per month. Therefore, approximately 94% and 70% from the positive and negative deviations, respectively, from the equilibrium, will persist in the following months. Finally, regarding the pair GR-IT, with Italy forcing, results suggest that positive and negative shocks are transmitted with the same magnitude. Thus in this case, the long-run relation is confirmed to be linear and is represented as shown in *Table 17*.

Table 16. MTAR non-linear cointegration and asymmetry test

Variables		**Non-linear cointegration and asymmetry**					
Dependent	**Independent**	***T***	***ρ1***	***ρ2***	***ρ1=ρ2=0***	***ρ1=ρ2***	***k***
GR	ES	-0.035	-0.081** (-0.041)	-0.359*** (0.065)	16.060***	13.730***	2
GR	IT	-0.046	-0.161*** (0.044)	-0.362*** (0.085)	14.469***	4.691***	2
IT	ES	-0.029	-0.061** (0.029)	-0.296*** (0.056)	16.122***	13.496***	2

Notes:
T denotes the threshold value.
k denotes the optimal lag structure that was selected based on the Schwarz Information Criterion.
The tests have been performed using code provided by Enders and Siklos (2001) on Eviews software, V12.
ρ1 and ρ2 denote the coefficients of asymmetric adjustment.
ρ1=ρ2=0 represents the null hypothesis of no cointegration and the critical values derive from Enders and Siklos (2001) for significance level 1%: GR-ES 10.470, GR-IT 10.670, and IT-ES 10.534.
ρ1=ρ2 represents the null hypothesis of symmetry and the critical values for significance level at 1% are: GR-ES 11.545, GR-IT 11.576., and IT-ES 11.641.
The simulation at critical values for 1% significance level was done with 10,000 replications.
In () the standard errors are presented.
*** and ** denote the rejection of the null hypothesis at significance level 1 and 5%, respectively.

4.4.4.7 The Law of One Price and Error Correction Model

The previous step has confirmed the existence of strong long-run relations for all three examined pairs, and the presence of asymmetries in two of the pairs, GR-ES, and IT-ES. Therefore, the LOP is rejected by definition for these price pairs due to the asymmetric pattern. In terms of the price pair GR-IT, a symmetric pattern allows the examination of the LOP through a Wald test on the long-run coefficients of *Table 17*. Results presented in the bottom part of *Table 17* confirm the presence of unitary elasticity (C1=1) and suggest that the LOP holds in its strong version (C0=0). In addition, the top part of *Table 18* presents the estimation of a symmetric error correction model (ECM) for the pair GR-IT to explore the dynamics of the model. Moreover, asymmetric error correction models (AECM) are estimated for the pairs GR-ES and IT-ES in *Table 18,* where the values δ_1 and δ_2 represent the adjustment coefficients to positive and negative deviations from the threshold value – t, respectively.

The results for the AECM agree with the MTAR results for pairs GR-ES and IT-ES. In particular, virgin olive oil (VOO) wholesalers in Greece respond quicker (approximately 40% per month) when prices in Spain worsen, compared to a slower response from Greece (approximately 6.9% per month) when prices in Spain improve. This means that GR prices decrease faster in response to ES price decreases, compared to GR price increases which take place slower in response to ES price increases. In addition, based on the threshold value which represents the transaction costs, prices between GR and ES should differ by at least 3.5% before the adjustment process commences. Similarly, for the price pair IT-ES, results suggest that wholesalers in Italy respond quicker (approximately 23.6% per month) when prices in Spain decrease, compared to when prices in Spain increase where Italy's response is slower (approximately 6.1% per month).

Moreover, in terms of the threshold value for this pair, prices in IT and ES should differ by at least 2.9% in order for the adjustment process to the new equilibrium to commence.

In terms of the symmetric ECM for the price pair GR-IT, the error correction term is equal to -0.130 which is negative and statistically significant. This means that, in case of a price shock in Italy, any deviations from the long-run equilibrium will be corrected on a monthly rate of 13.04%. Therefore, it will take approximately 8 months for prices to reach a steady state.

Also, in terms of past prices, these seem to relatively affect future VOO prices in both Greece and Italy to a certain extent. Specifically, for the pair GR-ES, the second lag in the price differences of Greek VOO affects Greek VOO prices negatively by 0.170, whereas the first lag in the price differences of Spanish VOO affects Greek VOO prices positively by 0.240. The values for the first lag of Greek VOO and second lag of Spanish VOO prices are not statistically significant, which means that these do not affect Greek VOO prices in the short run. Similarly, for the pair IT-ES, only the first lags in the price differences of Italian and Spanish VOO seem to affect Italian VOO prices positively by 0.238 and 0.185, respectively, since the values for the second lags of both countries are not statistically important, thus they do not affect Italian VOO prices in the short run.

Table 17. Symmetric Error Correction Model and Wald tests for Granger Causality

$\Delta Y_t = a_0 + \sum_{i=1}^{p} a_1 \Delta Y_{t-i} + \sum_{i=1}^{p} \beta_2 \Delta X_{t-i} + \delta_1 \Delta_{\mu-1} + \varepsilon_t$		
Country	GR-IT	
Coefficients	a_0	0.001 (0.331)
	a_1	0.029 (0.426)
	a_2	-0.178*** (-2.600)
	β_1	0.283*** (3.397)
	β_2	0.061 (0.706)
	δ	-0.130*** (-3.111)
Wald test	***Short-Run***	*F*(1.266)=17.546 [0.000]
	Law of One Price	*Unitary Elasticity F*(1.266)=1.617 [0.204] *LOP F*(1.266)=0.053 [0.817]

Notes:
The model VECM includes two lags for each variable.
The test has been performed using Eviews software, V12.
In () the t-statistics are provided, while p-values are shown in [].
***, ** and * denote the significance levels 1, 5 and 10%, respectively.

Table 18. Asymmetric Error Correction Model and Wald tests for Cointegration, Asymmetry and Short-run relation

$\Delta Y_t = a_0 + \sum_{i=1}^{p} a_1 \Delta Y_{t-i} + \sum_{i=1}^{p} \beta_2 \Delta X_{t-i} + \delta_1 I_t \Delta_{\mu-1} + \delta_2 (1 - I_t) \Delta\mu_{t-1} + \varepsilon_t$			
Country		GR-ES	IT-ES
Coefficients	a_0	-0.002 (-0.839)	0.001 (0.426)
	a_1	0.120* (1.890)	0.238*** (3.222)
	a_2	-0.171*** (-2.836)	0.025 (0.345)
	β_1	0.238*** (2.944)	0.185** (2.289)
	β_2	0.116 (1.352)	-0.076 (-0.951)
	δ_1	-0.069 (-1.604)	-0.061* (-3.529)
	δ_2	-0.402*** (-5.998)	-0.236*** (-1.733)
τ-value		-0.035	-0.029
Wald Tests	$H_0: \delta_1 = \delta_2 = 0$ **No Cointegration**	*F*(2.258)=18.724 [0.000]	*F*(2.258)=7.788 [0.000]
	$H_0: \delta_1 = \delta_2$ **Symmetry**	*F*(1.258)=18.411 [0.000]	*F*(1.258)=5.250 [0.022]
	Short Run	*F*(2.258)=6.952 [0.001]	*F*(2.258)=2.675 [0.070]

Notes:
The asymmetric models VECM include two lags for each variable.
The tests have been performed using code provided by Enders and Siklos (2001) on Eviews software, V12.
In () the t-statistics are provided, while p-values are shown in [].
***, ** and * denote the significance levels 1, 5 and 10%, respectively.

4.4.5 Summary of Findings - VOO

The first part of this empirical chapter investigates the price relations between the three main producer countries of virgin olive oil (VOO) in Europe; namely, Spain, Italy, and Greece. First, some preliminary tests were performed to establish the level of integration between the examined countries, which was done through various unit root tests. Since a central market was not pre-determined, the multivariate Johansen cointegration test followed to establish the number of cointegrating vectors and thus the country pairs that demonstrate long-run relations. To define the direction of causality and establish the central market, the non-linear causality test proposed by Diks and Panchenko (2006) was performed.

Causality test revealed that Spain (ES) has been identified as the central olive oil market in the EU since it was found that price changes in ES cause changes in the prices for both Greece (GR) and Italy (IT), whereas IT only causes GR. The leading role of ES can be ascribed to its status as the largest producer and exporter of olive oil in the EU. Similar results were found by Fousekis and Klonaris (2002) who concluded that Spain leads price formation. Although Emmanouilides *et al.* (2014) concurred with the notion that ES assumes the lead role in determining price formation in GR, they posited that IT functions as the central market, as it exerts influence on both Spain and Greece owing to its principal import status; a perspective that is also upheld by Serra *et al.* (2006b) concerning the poultry markets in the EU. It should be noted, however, that

Emmanouilides *et al.* (2014) focused on extra virgin and lampante olive oil, while the present study pertains to the analysis of virgin olive oil.

All examined pairs exhibited strong and stable long-run relationships which is confirmed through the cointegration analysis results. Nonetheless, the cointegration test conducted in this study demonstrated that the GR-IT pair displayed the most robust long-term relationship among the three pairs, likely attributable to the significant trading activity between these two nations, with almost 80% of Greece's olive oil exports being directed to Italy (European Commission, 2021c). In addition, they are closer in distance compared to the other pairs which indicates that these markets demonstrate higher level of dependence in comparison to the other pairs. These results are in line with Fousekis and Klonaris (2002) for VOO, and for EVOO as per Fousekis and Klonaris (2002), whereas Panagiotou (2015) also confirmed the high price dependence of Italian olive oil bottling industry to exports from GR and ES. High price dependence is also confirmed by Hamulczuka *et al.* (2019) in other edible oil markets such as UK and EU rapeseed oil markets, suggesting that certain EU CAP reforms have been effective towards market integration. Moreover, stable long-run relationships were found for pork (Fousekis, 2015), salmon (Asche *et al.*, 2007) and salted cod EU markets (Menezes and Dionísio, 2008). Another factor that strengthens market integration in the EU markets, and in particular olive oil, may be its lower perishability compared to other agricultural products, such as dairy markets. Specifically, no cointegration is found between the EU dairy markets and Oceania (OC) (Newton, 2016; Fousekis *et al.*, 2016; Fousekis and Grigoriadis, 2016a), and low degree of market integration is established between EU cow milk markets (Bakucs *et al.*, 2019), and skim milk powder among the USA, EU, and OC (Fousekis and Grigoriadis, 2016a). This can be explained by the fact that different levels of perishability can affect the stability of information flow between the markets, thus affecting market integration (Santeramo and Cramon-Taubadel, 2016; Hillen, 2021). On an international level, strong evidence of market integration was found by Nkang *et al.* (2008) for palm oil markets between Ikom and Akampa, and Sekhar (2012) for groundnut and mustard oil between Indian and international markets. Overall, the results of the present study in terms of market integration are in line with literature, which shows that EU agricultural markets exhibit high price dependence in the long run.

To increase the validity of the outcomes, triangulation of methods was performed by applying another cointegration test, accounting for potential structural breaks which may influence the long-run relation of the price pairs. The Gregory-Hansen test also confirmed strong price dependence between the examined pairs and has revealed the years when the structural breaks were identified. These were between 2013 and 2018 for all pairs, whereby for the pair ES-IT additional breaks were identified between 2003-2004. While the purpose of this study was not to analyse specific events that may coincide and explain the structural breaks, there are some indications that derive from the literature review chapter of this study. In 2013 there was a CAP reform (2013-2021) which focused on reinforcing the competitiveness of the EU olive oil sector. This included actions and measures to promote sustainability and the provision of financial support to encourage the productive use of land. These are factors that affect the production of olive oil, which can consequently affect the stability of the relationships between the countries. The additional structural break that was identified for ES-IT in 2003-2004 may also be attributed to a CAP reform. Specifically, the 2003 CAP Reform (2003-2013) abolished the production-led subsidies and replaced this by income support that is dependent on healthier, safer, and more environmentally-friendly practices (European Commission, 2021b). This may have discouraged some of the olive oil farmers, however, at the same time the European Commission decided to introduce production aids in the form of a budgetary envelope for each State member that would be dedicated to providing support to the olive grove on a by tree or by hectare basis and not on a production basis, which aimed to preserve the olive trees and the environment (Karey, 2006). This in turn may have affected production of olive oil in these markets during 2003-2004. Similarly, the unit root tests that were performed to consider structural breaks identified breaks in 2006 and 2008 for ES, 2006, 2013 and 2014 for IT and 2006, 2017 and 2018 for GR. Literature suggests that the structural breaks in ES may be linked to extreme weather conditions. Specifically, the olive oil prices in ES peaked in 2006 and 2008 due to unusually hot weather conditions and decreased production due to extended droughts (Feeny, 2015; Mullaney, 2013). In the case of structural breaks being identified in the price series of Italian olive oil, these can be attributed to the decrease in olive oil production in 2006 as a result of a standard crop rotation which is aimed to let trees rest and led to an increase in olive oil imports in order to satisfy demand (The New York Times, 2006). In addition, the structural break that was identified in 2013-2014 can be a result of decreased production due to the crops in Italy being hit by *Xylella Fastidiosa* (Burgen, 2014; Feeny, 2015). Moreover, the structural break in 2018 in the GR olive oil price series reflects an oversupply of olive oil which resulted in sudden price decreases. It appears that GR had difficulty in utilising this surplus in the markets, since IT had bought tax-free olive oil from Tunisia, as well as due to an expected bigger yield in ES, tempted big wholesalers in IT to delay purchasing olive oil in anticipation of cheaper olive oil from ES (OOT, 2018).

Regarding the pattern of price transmission, this was found to be asymmetric in the majority of pairs, indicating that positive and negative shocks are transmitted with a different magnitude between spatially-separated markets. Specifically, negative shocks in the ES olive oil prices are transmitted to IT and GR wholesale prices with a higher magnitude (price transmission elasticity of negative price shocks is greater than 1% compared to the elasticity of positive price shocks) than potential positive shocks in the prices of ES. Therefore, producers of olive oil in IT and GR are more likely to be "harmed" by price reductions in wholesale olive oil prices in ES than to benefit from price increases. Contrastingly, consumers in IT and GR are more likely to benefit from price decreases in ES olive oil prices than being "harmed" by price increases in the prices of ES olive oil. Only in the case of IT and GR (with IT forcing), price transmission is found to be symmetric, which indicates that price increases and price decreases in IT are transmitted to GR with the same magnitude, thus no country profits at the expense of the other. This may be due to the fact that GR and IT are neighbouring countries with a strong trading relationship in terms of olive oil trade transactions (Grigoriadis *et al.*, 2016). However, since the majority of the examined pairs reveal price transmission asymmetries, the EU olive oil markets as a whole can be characterised by inefficiencies. This is also confirmed by Fousekis and Klonaris (2002) who concluded to the same results for both extra virgin and virgin olive oil markets. Similar findings have been reached between EU and Ukrainian rapeseed oil markets (Hamulczuka *et al.*, 2019), which in combination with the results for olive oil markets suggest that overall the edible oil markets in the EU are inefficient. Considering other agricultural products in the EU such as pork, Fousekis (2015) established the presence of asymmetries between four of the five examined EU markets due to factors such as market power, physical distance, less intensive trade, and exchange rates, since some of the examined markets have not adopted Euro as their currency. However, a symmetric relationship was identified between ES and Germany (DE), which are the two largest pork producers in the EU.

In terms of the speed of adjustment to equilibrium, the examined VOO markets respond significantly to changes in wholesale prices in ES below the threshold price. This means that wholesalers in IT and GR reduce their prices quicker than wholesalers in ES in order to maintain their share in the market. The determination of the threshold values is a very significant finding of the present study as they reflect the threshold of the transaction costs and indicate the values which any deviations should surpass in order for the adjustment to equilibrium process to commence (Ankahamh-Yeboah, 2012). There is lack of information on transaction costs which are very difficult to capture. However, this study manages to determine the threshold values through the MTAR model. In particular, for ES-GR the threshold value is calculated -0.035. This means that for the adjustment to equilibrium process to commence, prices between ES and GR should differ by at least 3.5%. Similarly the threshold value for ES-IT is -0.029, thus prices should differ by at least 2.9% before the adjustment process begins to achieve a new equilibrium. Considering IT-GR, a symmetric price transmission pattern was confirmed; therefore any deviations from the long-run equilibrium following a price shock in IT can take approximately 8 months to be corrected, before they reach a new equilibrium point. Furthermore, the longest time of adjustment to equilibrium, based on the results of this study, is recorded for ES-IT where it takes around 16 months to adjust to positive deviations and around 3 months to negative deviations compared to 12 months and 3 months respectively for the pair GR-ES. This can further support the point for a lower degree of price dependence between ES and IT.

Trade intensity and physical proximity are some of the main causes of asymmetry in the EU olive oil markets. This is clearly evident, especially in the case of ES-GR. While ES is the largest olive oil exporter in the EU, only 0.1% of its exports go to GR and GR exports to ES only 1.9% of its olive oil (European Commission, 2021c). Contrastingly, in the case of IT-GR, where there is higher trade activity a symmetric pattern is confirmed, since 77.5% of GR exports go to IT (European Commission, 2021c). In addition, physical distance is longer between ES-IT and ES-GR meaning that price shocks may be transmitted more quickly between markets that are closer geographically and vice versa, which explains the presence of asymmetries in these price pairs. This was also suggested by Grigoriadis *et al.* (2016) who confirmed that these two factors play a significant role in the price transmission process. Another factor that affects the pattern of price transmission in the case of ES-IT is a unilateral relationship, whereby ES consistently acts as the net exporter and IT the net importer (Goodwin and Piggott, 2001; Emmanouilides and Fousekis, 2012), which is shown to encourage asymmetries. Moreover, production-related factors can cause asymmetries in the price transmission process such as adverse weather conditions (Bor *et al.*, 2013). For example, extended periods of drought can affect olive groves and the production of olive oil, thus cause price shocks in the affected areas. Noteworthy is the role that market structure plays in asymmetric price transmission. In the case of olive oil markets, this is particularly important as it can be described as oligopolistic, meaning that there is high market concentration. While at local level ES, IT and GR have a large number of small-level producers, the markets are still dominated by few large corporations or co-ops that manage production, storage, and bottling (CBI, 2020). Furthermore, consumer preferences can result in asymmetries in the EU olive oil markets in relation to product characteristics and specifically quality. ES, IT, and GR are not only the largest producers and exporters of olive oil in the EU, but also the largest consumers of olive oil. However, the consumer preferences in each country in terms of consumption differ which may lead to asymmetries. While the majority of consumers in ES consume virgin and refined olive oils (approximately 61%), IT (more than 80%) and GR (57%) consumers prefer extra virgin olive oil (Bettini, 2017; OOT, 2020; Mesa, 2021; Statista, 2021; OOT, 2021). This can affect demand and/or production of the preferred olive oil quality in each market whereby positive and negative price shocks are transmitted at different speeds.

The confirmation of asymmetric price transmission in relation to the spatial integration of the pairs ES-GR and ES- IT, leads to the rejection of the Law of One Price (LOP) by definition for these pairs due to the presence of asymmetries. Since the majority of examined pairs in the present study reject the validity of the LOP, the EU olive oil markets are considered inefficient. This rejection of the LOP in these markets can be attributed to transportation costs that are non-stationary, as was confirmed by Fousekis and Klonaris (2002) for olive oil markets in ES, IT, and GR. Moreover, other studies that examined the LOP for other agricultural markets, such as Baffes (1991) for wheat and wool in US, Canada, Australia, and UK, attribute inefficiencies to transportation costs, Rumánková (2012) for pig and beef markets in the Czech Republic due to transaction costs, while Fousekis (2007) rejected the LOP in the EU pork and poultry markets due to collusive behaviour being present in these markets. Since the majority of examined pairs in the present study reject the validity of the LOP, the EU olive oil markets are considered inefficient. In general, there are mixed results in agricultural markets in relation to the validity of the LOP, which is also the case for olive oil markets as the present study has also confirmed the validity of the LOP for one of the pairs. In the case of IT-GR where the pattern of price transmission is found to be symmetric, the Law of One Price is tested through a Wald test, which shows that the LOP holds in its strong version. This strengthens the argument that olive oil prices in IT and GR tend to comove in the long run. Similar results were found in literature for pork markets between Germany and ES who are the largest pork meat producers in the EU (Emmanouilides and Fousekis, 2012).

4.5 An empirical examination of price relations in EU olive oil markets: Extra virgin olive oil markets (EVOO)

The next part explores the price relationships between olive oil markets in Spain (ES), Italy (IT), and Greece (GR) in relation to the extra virgin olive oil quality. This was pursued using the following econometric tests: the ADF (Dickey and Fuller, 1981) and PP (Phillips and Perron, 1988) unit root tests, the Zivot-Andrews (1992) and Perron (1989) unit root tests with one structural break, and the Lee and Strazicich (2003; 2004) unit root test with one and two structural breaks. The following steps in the empirical analysis included the Hacker and Hatemi-J (2010) bootstrap causality test and the non-linear Diks and Panchenko (2006) causality test and determined the direction of causality. Moreover, the Non-linear Autoregressive Distributed Lag (NARDL) cointegration test explored the long and short-run relations considering for asymmetries in price transmission process.

4.5.1 Descriptive Statistics

Figure 29 presents the extra virgin olive oil prices at wholesale level in ES, IT and GR for the period 01/2000-04/2022, expressed in natural logarithms. Based on this, it is inferred that despite significant volatility in prices over the observed period in all three nations, there is evidence of a shared trend. Any slight variations in the degree of price fluctuation across the three markets can plausibly be attributed to disparities in the supply or demand of extra virgin olive oil at any given time. Additionally, IT extra virgin olive oil exhibits a tendency to command higher prices relative to ES and GR counterparts.

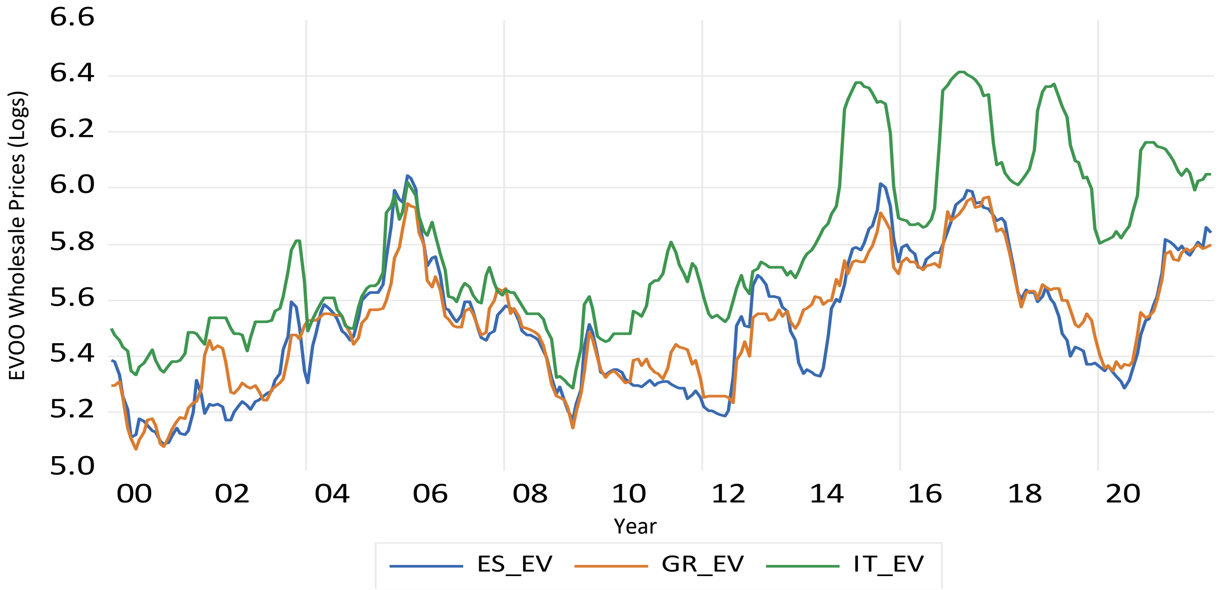


Figure 29. Natural logarithms of Extra Virgin olive oil wholesale prices - ES, IT, GR

This is also shown in *Table 20,* where IT recorded a higher mean ($\bar{x}$ = 338.63) than ES ($\bar{x}$ = 254.34) and GR ($\bar{x}$ = 254.82), which may be due to the fact that IT imports high amounts of olive oil in bulk from ES and GR which it then refines or re-bottles, meaning that their overall cost of production is higher as a result of higher transportation costs. In particular, this is also supported by the maximum and minimum values of the three countries. According to *Table 19*, the maximum price for IT extra virgin olive oil reached €609.95/100 kgs in the examined period which is substantially higher than the maximum price of ES (€421.22/100 kgs) and GR (391.60/100 kgs) extra virgin olive oil. The same tendency is shown at minimum prices recorded by the three countries whereby the minimum price recorded by IT was again higher than the minimum prices recorded by ES and GR (IT €197.50/100 kgs, ES €162.09/100 kgs, and GR €158.82/100 kgs). The standard deviation values for all three markets are low (<1); ES=0.24, IT=0.29 and GR=0.21, which indicate low variance from the mean. Data series for ES, IT and GR demonstrate slight positive skewness with values of 0.30, 0.57 and 0.11, respectively. Based on these values, the majority of price observations are found within the lower price range. In terms of kurtosis, all data series exhibit kurtosis values that are lower than 3, and therefore the distribution is characterised as platykurtic. Furthermore, the null hypothesis of Jarque-Bera test for normality can be rejected in the case of ES and IT ($p<0.05$) indicating non-normal distribution, whereas the null of normality cannot be rejected in the case of GR ($p>0.05$) indicating normal distribution.

Table 19. Descriptive statistic for Extra Virgin olive oil prices in raw form and natural logarithms

	ES_EV	L_ES_EV	IT_EV	L_IT_EV	GR_EV	L_GR_EV
Mean	254.3439	5.508867	338.6299	5.778321	254.8230	5.518120
Maximum	421.2235	6.043163	609.9493	6.413376	391.6019	5.970246
Minimum	162.0935	5.088173	197.5000	5.285739	158.8250	5.067803
Std. Dev.	63.76670	0.242298	109.3841	0.298453	54.70155	0.211747
Skewness	0.676868	0.302132	0.995641	0.568927	0.527870	0.108760
Kurtosis	2.550842	2.105129	2.961684	2.291814	2.634972	2.334566
Jarque-Bera	22.71684	13.01955	44.29450	20.05802	13.93414	5.472972
Probability	0.000012	0.001489	0.000000	0.000044	0.000942	0.064798
Observations	268	268	268	268	268	268

4.5.2 Unit Root Tests

The ADF (Dickey and Fuller, 1981) and PP (Phillips-Perron, 1988) unit root tests were performed to determine the level of integration of the variables. Two models have been tested, one including only an intercept and the other including intercept and trend in the levels and first differences. The results are shown in *Table 20*. The critical values were provided by MacKinnon (1996) for 1 and 5% significance levels and are reported as a footnote under *Table 21*. In addition, the optimal lag length was selected based on the Akaike Information Criterion for the ADF test and using the Newey-West Bandwidth method for the PP test.

Both unit root tests reach similar conclusions, where all price series (ES, IT and GR) are found to be integrated of order 1, I(1), and are stationary in the first differences at 1% significance level. This is the case when the model includes an intercept, and an intercept and trend.

Table 20. ADF (1981) and PP (1988) unit root tests

Intercept									
Variable	**ADF**		**PP**		**Variable**	**ADF**		**PP**	
	t-value	*k*	Adj. t-Stat	*k*		t-value	*k*	Adj. t-Stat	*k*
ES	-2.867	5	-2.005	4	ΔES	-9.891***	1	-9.114***	15
IT	-1.334	13	-2.125	6	ΔIT	-7.811***	12	-10.066***	7
GR	-2.274	1	-2.070	5	ΔGR	-11.610***	0	-11.612***	1
Intercept and Trend									
Variable	**ADF**		**PP**		**Variable**	**ADF**		**PP**	
	t-value	*k*	Adj. t-Stat	*k*		t-value	*k*	Adj. t-Stat	*k*
ES	-3.115	5	-2.452	4	ΔES	-9.872***	1	-9.100***	15
IT	-1.929	13	-3.225	6	ΔIT	-7.801***	12	-10.045***	7
GR	-2.808	1	-2.571	5	ΔGR	-11.588***	0	-11.591***	1

Notes:
Δ denotes first differences.
ADF and PP denote the Augmented Dickey-Fuller unit root test and the Phillips-Perron unit root test, respectively.
k denotes the optimal lag structure of the ADF test that was selected based on the Akaike Info Criterion, while the number of lags for the PP test was determined based on Newey-West Bandwidth method with Bartlett kernel.
The tests have been performed on Eviews software, V12.
The critical values for the ADF and PP unit root tests in the intercept are -3.45 and -2.87 for significance level 1 and 5%, respectively, while the critical values in both the intercept and trend are -3.99 and -3.42 for significance level 1 and 5%, respectively (MacKinnon, 1996).
*** and ** denote the rejection of the null hypothesis of the series having a unit root at significance level 1 and 5%, respectively.

4.5.3 Unit Root with structural breaks

To ensure the validity of the results, the Zivot-Andrews (1992) and Perron (1997) unit root tests with one structural break are performed. *Table 21* demonstrates the findings from the tests when the model includes a constant, and a constant and trend in the levels and first differences. The critical values are presented as a footnote in *Table 21* for 1 and 5% significance levels and the optimal lag structure was established based on the Akaike Information Criterion for the Zivot-Andrews test, and the Schwarz Information Criterion for the Philips Perron test. The findings confirm that all price series (ES, IT and GR) have a unit root in the levels with one structural break but are stationary when they are expressed in the first differences, thus are characterised as being integrated of order 1, I(1). The Zivot-Andrews test has detected the structural breaks for ES in 2006, for IT in 2006 and 2009, and for GR in 2006, while the Philips Perron test has identified the breaks for ES in 2005 and 2006, for IT in 2014, and for GR in 2006 and 2016.

Table 21. Zivot-Andrews (1992) and the Perron (1997) unit root tests with one structural break

Intercept – Levels							**Intercept – 1st Difference**						
Variable	**Zivot-Andrews**			**Perron**			**Variable**	**Zivot-Andrews**			**Perron**		
	T_B	k	t-statistic	T_B	k	t-statistic		T_B	k	t-statistic	T_B	k	t-statistic
ES	2008M02	2	-3.009	2006M01	1	-3.531	ΔES	2006M02	4	-6.608***	2006M01	4	-6.850***
IT	2013M12	1	-4.657	2013M11	1	-4.642	ΔIT	2009M06	0	-10.248***	2014M11	0	-11.044***
GR	2008M02	1	-3.372	2008M01	1	-3.373	ΔGR	2006M02	0	-11.855***	2006M01	0	-11.977***
Intercept and Trend – Levels							**Intercept and Trend – 1st Difference**						
Variable	**Zivot-Andrews**			**Perron**			**Variable**	**Zivot-Andrews**			**Perron**		
	T_B	k	t-statistic	T_B	k	t-statistic		T_B	k	t-statistic	T_B	k	t-statistic
ES	2006M04	2	-3.730	2006M01	1	-4.375	ΔES	2006M02	4	-6.679***	2005M10	0	-10.202***
IT	2014M08	1	-4.836	2014M07	1	-4.841	ΔIT	2006M02	0	-10.247***	2014M11	0	-10.992***
GR	2006M04	1	-3.874	2006M01	1	-3.828	ΔGR	2006M02	0	-11.976***	2016M12	0	-12.053***

Notes:
Δ denotes first differences.
T_B denotes the time of the structural break.
k denotes the optimal lag structure of the Zivot-Andrews test that was selected based on the Akaike (AIC) Information Criterion, while the number of lags for the Perron test was determined based on the Schwarz Information Criterion.
The tests have been performed using Eviews software, V12.
The critical values for the Zivot-Andrews unit root test with one structural break in the intercept are -5.34 and -4.93 for significance level 1 and 5%, respectively, while the critical values in both the intercept and trend are -5.57 and -5.08 for significance level 1 and 5%, respectively.
The critical values for the Perron unit root test with one structural break in the intercept are -5.92 and -5.23 for significance level 1 and 5%, respectively, while the critical values in both the intercept and trend are -6.32 and -5.59 for significance level 1 and 5%, respectively.
*** and ** denote the rejection of the null hypothesis of the series having a unit root with a structural break at significance level 1 and 5%, respectively.

Furthermore, the Lee-Strazicich (2003; 2004) unit root tests are performed accounting for one and two structural breaks in the series and the results are presented in *Tables 22* and *23*, respectively. The upper parts of the *Tables* demonstrate the results from the tests when they are performed with model A which includes an intercept, and the bottom parts present the results when the tests are performed with model C which includes a trend. Also, the optimal lag structure was selected based on a general to specific procedure as proposed by Lee and Strazicich (2003; 2004).

These tests further confirm the findings that price series ES, IT and GR are stationary with one and with two structural breaks in the first differences at 1% significance level, and are therefore integrated of order 1, I(1). The structural breaks based on the Lee-Strazicich (2003; 2004) unit root tests are identified in 2003, 2005, 2010, 2018 and 2019 for ES, in 2006, 2015, 2016, 2017 and 2019 for IT, and 2002, 2006, 2011, 2015 and 2018 for GR.

Table 22. Lee-Strazicich (2004) unit root test with one structural break

Model A – Levels				**Model A – First Difference**			
Variable	T_B	**K**	**t-statistic**	**Variable**	T_B	**k**	**t-statistic**
ES	2012M08	5	-3.154	ΔES	2010M09	14	-6.199***
IT	2014M10	13	-2.548	ΔIT	2016M04	12	-7.582***
GR	2008M6	6	-3.150	ΔGR	2018M02	3	-7.406***
Model C – Levels				**Model C – First Difference**			
Variable	T_B	**K**	**t-statistic**	**Variable**	T_B	**k**	**t-statistic**
ES	2012M08	5	-3.190	ΔES	2018M01	14	-6.796***
IT	2014M06	13	-2.818	ΔIT	2015M06	12	-8.238***
GR	2008M11	6	-3.273	ΔGR	2011M09	3	-7.447***

Notes:
Δ denotes first differences.
T_B denotes the time of the structural break.
k denotes the optimal lag structure of the Lee and Strazicich (2004) test that was selected based on a general to specific procedure.
The critical values are provided by Lee and Strazicich (2004).
The test was performed using GAUSS code produced by Lee-Strazicich (2004).
*** and ** denote the rejection of the null hypothesis of the series having a unit root with one structural break at significance level 1 and 5%, respectively.

Table 23. Lee-Strazicich (2003) unit root test with two structural breaks

Model A – Levels					**Model A – First Difference**				
Variable	T_{B1}	T_{B2}	**k**	**T-Statistic**	**Variable**	T_{B1}	T_{B2}	**k**	**T-Statistic**
ES	2006M09	2009M10	5	-3.384	ΔES	2010M12	2019M09	14	-6.411***
IT	2012M12	2014M10	13	-2.719	ΔIT	2017M12	2019M06	12	-7.990***
GR	2007M05	2008M11	6	-3.210	ΔGR	2006M04	2006M06	2	-9.353***
Model C – Levels					**Model C – First Difference**				
Variable	T_{B1}	T_{B2}	**k**	**T-Statistic**	**Variable**	T_{B1}	T_{B2}	**k**	**T-Statistic**
ES	2008M04	2017M07	5	-3.718	ΔES	2003M07	2005M09	1	-10.331***
IT	2008M01	2014M09	12	-4.330	ΔIT	2006M02	2015M06	12	-8.703***
GR	2008M01	2017M06	6	-4.011	ΔGR	2002M03	2002M06	0	-11.629***

Notes:
Δ denotes first differences.
T_{B1} and T_{B2} denote the time of the structural breaks.
k denotes the optimal lag structure of the Lee and Strazicich (2003) test that was selected based on a general to specific procedure.
The critical values are provided by Lee and Strazicich (2003).
The test was performed using GAUSS code produced by Lee-Strazicich (2003).
*** and ** denote the rejection of the null hypothesis of the series having a unit root with two structural breaks at significance level 1 and 5%, respectively.

4.5.4 Cointegration Analysis, Error Correction and Causality Tests

Following the determination of the order of integration and the presence of unit roots in the examined pairs, the direction of causality is then examined through the bootstrap causality test proposed by Hacker and Hatemi (2010). The results are shown on *Table 24*, and indicate that the causality is unidirectional from ES to GR, IT to ES and IT to GR. While the null hypothesis of no cause is rejected for the pairs ES-GR and IT-GR at 1% significance level, for the pair IT-ES the null hypothesis of Italy not causing Spain is rejected, however at 10% significance level. Therefore, this result should be interpreted with caution. Price relations are characterised by non-linearities which primarily arise from transaction costs (Serra *et al.*, 2006a; 2006b). In this vein, the Diks and Panchenko (2006) causality test is applied to consider non-linearities and in this respect triangulation of methods will increase validity of the outcomes. The test will be employed on the residuals deriving from the ARDL cointegration test and will be applied bi-directionally for each price pair.

Table 24. Bootstrap causality test by Hacker and Hatemi-J (2010)

H_0: Null hypothesis	W-stat	Critical Values			k
		1%	5%	10%	
ES does not cause GR	27.859***	8.688	5.904	4.573	2
GR does not cause ES	1.430	9.547	5.942	4.644	2
IT does not cause ES	5.609*	9.093	6.167	4.750	2
ES does not cause IT	2.007	8.916	6.046	4.673	2
GR does not cause IT	0.192	9.575	6.163	4.657	2
IT does not cause GR	21.783***	9.507	6.223	4.730	2

Notes:
k denotes the optimal lag structure that was selected based on the Schwarz Information criterion.
The test was performed using GAUSS code produced by Hacker and Hatemi-J (2010).
***, ** and * denote the rejection of the null hypothesis at significance levels 1, 5 and 10%, respectively.

4.5.4.1 Autoregressive Distributed Lag (ARDL) Cointegration test

Table 25 showcases the results from the ARDL cointegration bounds test, the estimated long-run coefficients as well as the diagnostic tests.

Table 25. ARDL cointegration test and long-run coefficients

ARDL model	Specification	F_{PSS}	t_{BDM}	Coefficient	SC	ARCH
ES → GR	(1, 1)	14.080***	-5.297***	0.837	9.536 (0.656)	11.662 (0.473)
GR → ES	(8, 8)	14.874***	-5.285***	0.998	11.963 (0.448)	24.084 (0.063)
IT → ES	(5, 1)	4.962*	-3.144**	0.557	9.806 (0.632)	22.838 (0.118)
ES → IT	(12, 1)	2.804	-2.222	0.615	14.233 (0.286)	11.005 (0.528)
IT → GR	(1, 11)	7.448**	-3.846***	0.582	10.184 (0.599)	12.545 (0.402)
GR → IT	(12, 7)	3.201	-2.437	0.967	16.460 (0.171)	8.870 (0.714)

Notes:
The symbol → indicates the direction of causality.
The ARDL specifications denote the optimal lag lengths that were selected based on the Schwarz Information Criterion.
The tests have been performed on Eviews software, V12.
For *k*=1, the critical value bounds at significance levels 1, 5, and 10% for F_{PSS} statistic are: 6.84 to 7.84, 4.94 to 5.73, and 4.04 to 4.78, respectively.
For *k*=1, the critical value bounds at significance levels 1, 5, and 10% for t_{BDM} statistic are: -3.42 to -3.82, -2.86 to -3.22, and -2.57 to -2.91 respectively.
The critical values were provided by Pesaran *et al.* (2001).
***, ** and * denote the rejection of the null hypothesis at significance levels 1, 5 and 10%, respectively.

According to the F_{PSS} and t_{BDM}, a long-run relation has been confirmed for the price pair ES-GR in both directions at 1% significance level, from IT to GR at 5% significance level and from IT to ES at 10% significance level. Specifically, for all examined pairs, apart from price pairs IT-ES (with ES forcing) and GR-IT (with IT forcing), the F_{PSS} statistics are greater and the t_{BDM} statistics are smaller than the upper bound critical values as per Pesaran *et al.* (1999). This means that the null hypothesis of no cointegration can be rejected; thus long-run relations have been established for these price pairs.

The long-run coefficients are also presented on *Table 25* and reveal stronger price dependence between the price pair ES and GR. In particular, for pair GR-ES (with ES forcing) the long-run coefficient is 0.837, suggesting that 1% increase in the prices of EVOO in Spain lead to 0.837% increase in the wholesale prices of EVOO in Greece. Reversely, the long-run coefficient for ES-GR (with GR forcing) is estimated at 0.998 which translates to 1% increase in the prices of GR causing an increase of 0.998% in the prices of EVOO in Spain. Regarding the long-run coefficients for the price pairs ES-IT (with IT forcing) and IT-ES (with ES forcing), these are calculated at 0.557 and 0.615, respectively, thus 1% increase in the prices of ES cause a larger percentage increase in the wholesale prices of EVOO in IT, than the other way round. Last, for the pair GR-IT (with IT forcing) and IT-GR (with GR forcing), it is found that 1% increase in Italian EVOO prices causes an increase by 0.582% in Greek EVOO prices, whereas 1% increase in Greek EVOO prices trigger an increase of 0.967% in Italian EVOO wholesale prices.

To determine the stability of the model and thus the validity of the findings, the model is tested for serial correlation (SC) and heteroskedasticity (ARCH). The results are shown in the last two columns of *Table 25* and confirm that the majority of the models exhibit no serial correlation or ARCH effects and are therefore deemed satisfactory. Although ARCH effects are identified in the diagnostic test for the ARDL model of the ES-GR (with GR forcing) pair, this is supported at 10% level of significance.

4.5.4.2 Diks and Panchenko (2006) causality test

Following the establishment of long-run cointegrating relations between the examined countries, the residuals are kept from the ARDL cointegration test and used to perform the Diks and Panchenko (2006) causality test. Based on the time series length (n>200), the bandwidth value (ε) is set at ε=1.50, as suggested by Diks and Panchenko (2005) and performed using one, two, three, four and five lags in each case.

The results are shown in *Table 26* and for the price pairs ES-GR and IT-GR, it is suggested that GR does not cause ES whereas ES causes GR at 5% and 10% level of significance, and GR does not cause IT whereas IT causes GR across all lags at 1,5 and 10% level of significance. For IT-ES, results indicate that the null hypothesis of no causal relationship between IT and ES cannot be rejected at any lag level.

Table 26. Diks and Panchenko Causality Test on ARDL Cointegration Residuals

K	Greece & Spain		Greece & Italy		Italy & Spain	
LX = LY	EL≠ >ES	ES ≠ > EL	EL ≠> IT	IT ≠> EL	IT ≠> ES	ES ≠>IT
1	-1.161 (0.877)	0.779 (0.218)	2.732*** (0.003)	2.661*** (0.003)	1.191 (0.116)	0.858 (0.195)
2	-0.003 (0.501)	1.681** (0.046)	1.845** (0.032)	2.181** (0.014)	1.212 (0.112)	0.951 (0.170)
3	-0.193 (0.576)	2.304** (0.010)	1.270 (0.101)	1.625* (0.052)	0.519 (0.301)	0.896 (0.185)
4	-0.721 (0.764)	1.871** (0.030)	0.824 (0.205)	1.620* (0.052)	0.419 (0.337)	0.402 (0.343)
5	-1.261 (0.896)	1.419* (0.077)	0.730 (0.232)	1.753** (0.039)	0.392 (0.347)	0.151 (0.440)

***, ** & * denote the rejection of the null hypothesis that LX does not cause LY at significance levels 1%, 5% and 10%, respectively.
In brackets the p-values are presented.
The tests have been performed using code provided by Diks and Panchenko (2006).
Symbol ≠ > means that X does not cause Y.
Symbol k denotes that optimal lag length.

4.5.4.3 Non-linear Autoregressive Distributed Lag (NARDL) Cointegration test

Relation between Greece and Spain, with Spain forcing

Having established the directions of price relations, EVOO price dependence is examined in GR and ES with ES forcing, through the NARDL model. Initially, model (a) assumes asymmetry both in the long and short run and results are compared with the upper bound critical values provided by Pesaran *et al.* (1999), using the lag length of *k*=1. According to the findings presented in *Table 27*, the $\mathrm{F_{PSS}}$ statistic (10.317) exceeds the corresponding upper bound critical value and the t_{BDM} statistic (-5.489) is less than the corresponding upper bound critical value at 1% level of significance. Thus, the null hypothesis of no cointegration can be rejected, confirming there is a long-run relation between GR and ES prices.

Table 27. Bounds testing for asymmetric cointegration

Statistics	GR - ES (ES forcing)	
	NARDL model with LR & SR asymmetry (a)	NARDL model with LR symmetry & SR asymmetry (b)
F_{PSS}	10.317***	14.656***
t_{BDM}	-5.489***	-5.364***

Notes:
***, ** and * denote the rejection of the null hypothesis of no cointegration at significance levels 1, 5 and 10%, respectively.
The tests have been performed using code provided by Sunder and Greenwood-Nimmo in Stata and Eviews, V12.
For *k*=1, the critical value bounds at significance levels 1, 5, and 10% for $\mathbf{F_{PSS}}$ statistic are: 6.84 to 7.84, 4.94 to 5.73, and 4.04 to 4.78, respectively.
For *k*=1, the critical value bounds at significance levels 1, 5, and 10% for t_{BDM} statistic are: -3.42 to -3.82, -2.86 to -3.22, and -2.57 to -2.91 respectively.
The critical values were provided by Pesaran *et al.* (2001).

Then, long-run and short-run symmetry are examined. Results in *Table 28* indicate that for the price pair GR and ES with ES forcing, W_{LR} equals 1.735 with p-value 0.189. This shows that the null hypothesis of symmetry cannot be rejected, therefore symmetry is established between GR and ES prices in the long run. Regarding the short run, W_{SR} is equal to 4.035 with p-value 0.045; therefore, the null hypothesis of symmetry can be rejected, and asymmetry is supported between GR and ES prices.

Table 28. Long-run and short-run asymmetry tests

Statistics	GR - ES (ES forcing)	
	NARDL model with LR & SR asymmetry (a)	NARDL model with LR symmetry and SR asymmetry (b)
W_{LR}	1.735 (0.189)	–
W_{SR}	4.035** (0.045)	4.983** (0.026)

Notes:
***, ** and * denote the rejection of the null hypothesis of symmetry at significance levels 1, 5 and 10%, respectively.
The tests have been performed using code provided by Sunder and Greenwood-Nimmo in Stata and Eviews, V12.
W_{LR} denotes the Wald test for the null hypothesis of long-run symmetry.
W_{SR} denotes the Wald test for the null hypothesis of short-run symmetry.
In brackets, the p-values are presented.

According to Greenwood-Nimmo and Shin (2013), when one or both of the null hypotheses of symmetry cannot be rejected, then the NARDL model should be re-estimated by adjusting the null hypothesis of symmetry in the new model. In the case of GR and ES with ES forcing, model (a) showed symmetry in the long run and asymmetry in the short run, therefore the NARDL model is re-estimated with model (b) considering the results from the default model (a). The results of model (b) are shown in the second columns of *Table 27* for cointegration and *Table 28* for symmetry. Particularly, the F_{PSS} statistic (14.656) exceeds the corresponding upper bound critical value and the t_{BDM} statistic (-5.364) is smaller than the corresponding upper bound critical value at 1% significance level. Thus, the null hypothesis of no cointegration can be rejected, indicating cointegration between GR and ES with ES forcing. Similarly, the model proceeds to re-examine the null hypothesis of short-run symmetry only using the re-adjusted model (b), since in the long run the null hypothesis of symmetry cannot be rejected in model (a). The results are shown in the second column of *Table 28*, where W_{SR} equals 4.983 with p-value 0.026, which confirm the results of model (a) which showed asymmetry between GR and ES with ES forcing in the short run. Overall, for the pair GR and ES with ES forcing, cointegration has been found with symmetry in the long run and asymmetry in the short run.

Table 29 presents the long-term coefficient and price transmission elasticity. The long-term coefficient is equal to 0.853. This means that 1% increase in the wholesale prices of EVOO in Spain leads to an increase by 0.853% in the wholesale prices of EVOO in Greece. Since symmetry was found in the long run in the previous stages of the NARDL test, unitary elasticity is also tested, which is a pre-requisite to test for the Law of One Price (LOP). This is pursued using Wald test on the long-run coefficients. Results show that the Wstat is equal to 6.614 with p-value (0.010), which means that the null hypothesis for unitary elasticity can be rejected and therefore the LOP cannot be tested in this case. To further validate this outcome, the strong version of the LOP is tested through a Wald test (μ=0) and the results further confirm that the strong version of the LOP does not hold.

Table 29. Long-term coefficient and price transmission elasticity

Greece - Spain (ES effect)	
βES,GR	0.853***
Wstat	6.614 (0.010)
μ=0	5.276 (0.022)

Notes:
β denotes the long-run coefficient.
The tests have been performed using code provided by Sunder and Greenwood-Nimmo in Stata and Eviews, V12.
Wstat denotes the Wald statistic for unitary elasticity.
μ=0 denotes the null hypothesis for the strong version of the law of one price.
In brackets (), the p-values are presented.

Table 30 presents the results from the estimation of the NARDL model (b) and the statistics and diagnostic tests for model accuracy purposes.

Table 30. NARDL model (b) estimation

Greece - Spain (ES effect)		
Variable	**Coefficient**	**Standard Error**
Constant	0.131	0.057
**LNGRt-1	-0.157***	0.029
LNESt-1	0.134***	0.025
ΔLNES+	0.484***	0.066
ΔLNES-	0.482***	0.088
ΔLNGRt-1	0.157***	0.049
ΔLNES+t-9	-0.142**	0.063
Statistics & Diagnostic tests		
R^2		0.453
R^2adj		0.440
Serial Correlation – SC		8.561 (0.739)
Heteroskedasticity - ARCH		11.003 (0.528)

Notes:
***, ** and * denote the rejection of the null hypothesis of symmetry at significance levels 1, 5 and 10%, respectively.
The tests have been performed using code provided by Sunder and Greenwood-Nimmo in Stata and Eviews, V12.
Symbols + and – denote the positive and negative deviations from equilibrium.

The short-term coefficients indicate that positive shocks in EVOO prices in ES are transmitted with a greater intensity to EVOO prices in GR than negative shocks.

Regarding the suitability of the model, R^2 and R^2adj show that variations in the independent variable (ES) help interpret the variations in the dependent variable (GR) at 45.3%. Further diagnostic tests are also carried out as shown in *Table 30*, which show that there is no correlation in the series and no ARCH effects, or heteroskedasticity.

Figure 30 presents the dynamic multipliers for the relationship of GR and ES with ES forcing. The blue and black lines demonstrate the relation between the countries following price shocks in the prices of the independent variable, in this case ES, whereas the red line shows the difference between positive and negative variations. Looking at the red line, it is deduced that it takes around 2 years and 10 months for the relation to return to equilibrium.

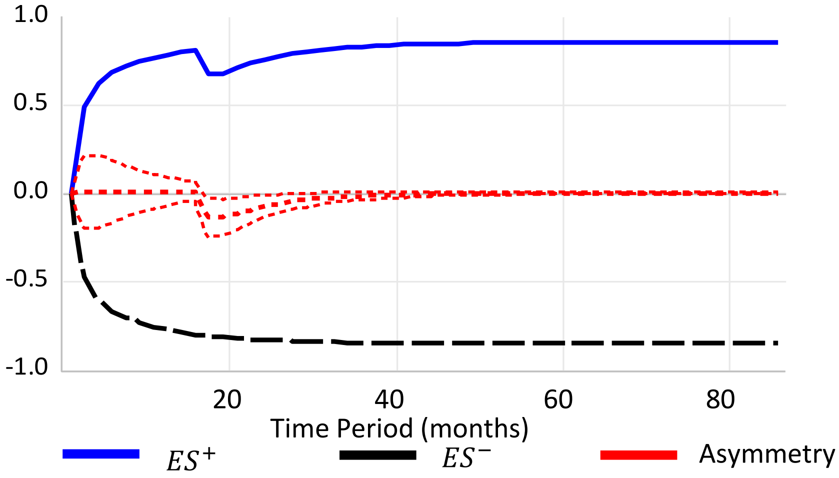


Figure 30. Dynamic Multipliers: Greece - Spain (Spain forcing)

The CUSUM of squares test is then applied, which demonstrates the stability of the NARDL model, as suggested by Pesaran and Pesaran (2009). *Figure 31* presents the results of the CUSUM of squares test. The CUSUM of squares test (blue line) does not exceed the critical bounds (red lines) at 5% significance level and therefore the coefficients are considered stable for the NARDL model.

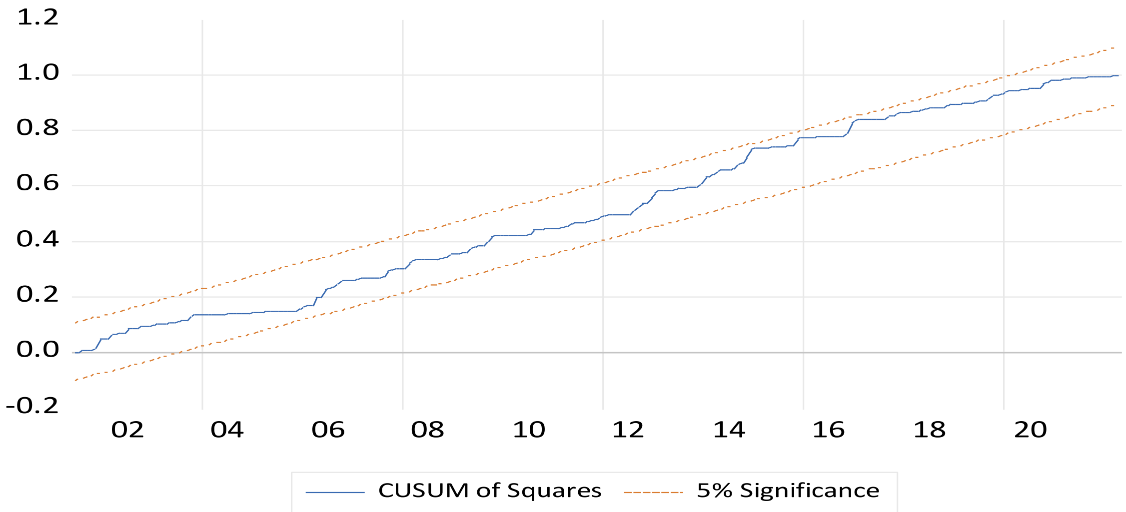


Figure 31. Cumulative sum (CUSUM) of squares test in model (b) with long-run symmetry and short-run asymmetry

Relation between Spain and Italy, with Italy forcing

Then, the relation between EVOO prices in ES and IT with IT forcing is investigated. *Table 31* presents the results of bounds testing for asymmetric cointegration. Initially, model (c) which indicates asymmetry in both the long and the short run is tested. The $\mathrm{F_{PSS}}$ statistic (4.224) shows that there is no cointegrating relation between EVOO prices in ES and IT. However, the t_{BDM} statistic (-3.489) indicates that there is cointegration at 5% significance level. Since the results are mixed, a further test is employed using model (d), where long and short-run symmetry is assumed. Model (d) shows that there is a weak cointegrating relation between ES and IT with IT forcing, since both the F_{PSS} (4.962) and the t_{BDM} (-3.144) statistics suggest that there is cointegration at 10% level of significance.

Table 31. Bounds testing for asymmetric cointegration

Statistics	ES - IT (IT forcing)	
	NARDL model with LR & SR asymmetry (c)	NARDL model with LR & SR symmetry (d)
F_{PSS}	4.224	4.962*
t_{BDM}	-3.489**	-3.144*

Notes:
***, ** and * denote the rejection of the null hypothesis of no cointegration at significance levels 1, 5 and 10%, respectively.
The tests have been performed using code provided by Sunder and Greenwood-Nimmo in Stata and Eviews, V12.
For *k*=1, the critical value bounds at significance levels 1, 5, and 10% for F_{PSS} statistic are: 6.84 to 7.84, 4.94 to 5.73, and 4.04 to 4.78, respectively.
For *k*=1, the critical value bounds at significance levels 1, 5, and 10% for t_{BDM} statistic are: -3.42 to -3.82, -2.86 to -3.22, and -2.57 to -2.91 respectively.
The critical values were provided by Pesaran *et al.* (1999).

Table 32 presents the findings for the presence of asymmetry between EVOO prices in ES and IT in both the long and the short run. According to the results, the null hypotheses for symmetry in the long run cannot be rejected since the W_{LR} statistic equals 0.098, with p-value 0.753. Similarly, in the short run, the W_{SR} statistic equals 0.243 with p-value 0.644, which suggests that there is symmetry in the long run and the short run.

Table 32. Long-run and short-run symmetry tests

Statistics	ES - IT (IT forcing)	
	NARDL model with LR & SR asymmetry (c)	NARDL model with LR & SR symmetry (d)
W_{LR}	0.098 (0.753)	–
W_{SR}	0.243 (0.644)	–

Notes:
***, ** and * denote the rejection of the null hypothesis of symmetry at significance levels 1, 5 and 10%, respectively.
The tests have been performed using code provided by Sunder and Greenwood-Nimmo in Stata and Eviews, V12.
W_{LR} denotes the Wald test for the null hypothesis of long-run symmetry.
W_{SR} denotes the Wald test for the null hypothesis of short-run symmetry.
In brackets, the p-values are presented.

In terms of the long-run coefficient, this is calculated as 0.557 as shown on *Table 33*. This indicates that 1% increase in the IT EVOO wholesale prices cause an increase by 0.557% in the ES EVOO wholesale prices. The outcome of symmetry enables unitary elasticity also to be tested through a Wald test. The Wstat is equal to 6.658 with p-value (0.010), indicating that the null hypothesis for unitary elasticity can be rejected. In turn, the LOP cannot be tested since the pre-requisite for the existence of unitary elasticity alongside symmetry cannot be confirmed in this case. To ensure the validity of this outcome, the LOP is tested and the result of μ=0 is 5.276 with p-value 0.022 which further validates that the strong version of the LOP does not hold.

Table 33. Long-term coefficient and price transmission elasticity

Spain – Italy (IT effect)	
βES,IT	0.557**
Wstat	6.658 (0.010)
μ=0	3.723 (0.054)

Notes:
β denotes the long-run coefficient.
The tests have been performed using code provided by Sunder and Greenwood-Nimmo in Stata and Eviews, V12.
Wstat denotes the Wald statistic for unitary elasticity.
μ=0 denotes the null hypothesis for the strong version of the law of one price.
In brackets (), the p-values are presented.

The NARDL results using model (d) are shown in *Table 34* along with statistics and diagnostic tests. According to the results, the variations in the prices of ES provide estimations of the prices of GR at 43.3%. In addition, there is no serial correlation or ARCH effects which confirm the suitability of the model.

Table 34. NARDL model (d) estimation

Spain – Italy (IT effect)		
Variable	**Coefficient**	**SE**
Constant	0.104	0.054
LNESt-1	-0.045***	0.014
LNITt-1	0.025**	0.011
ΔLNIT	0.353***	0.043
ΔLNESt-1	0.422***	0.055
ΔLNESt-2	-0.123***	0.047
ΔLNESt-5	0.141**	0.054
Statistics & Diagnostic tests		
R^2	0.433	
R^2adj	0.420	
SC	9.806 (0.632)	
ARCH	19.044 (0.087)	

Notes:
***, ** and * denote the rejection of the null hypothesis of symmetry at significance levels 1, 5 and 10%, respectively.
The tests have been performed using code provided by Sunder and Greenwood-Nimmo in Stata and Eviews, V12.
Symbols + and – denote the positive and negative deviations from equilibrium.

Figure 32 shows the dynamic multipliers for the price pair ES – IT with IT forcing. The blue and black lines, which represent the positive price shocks in the prices in IT and negative price shocks, respectively, abstain the same from the red line which represents the difference between positive and negative deviations. This means that the prices in ES react with the same intensity to positive and negative shocks in the prices of IT.

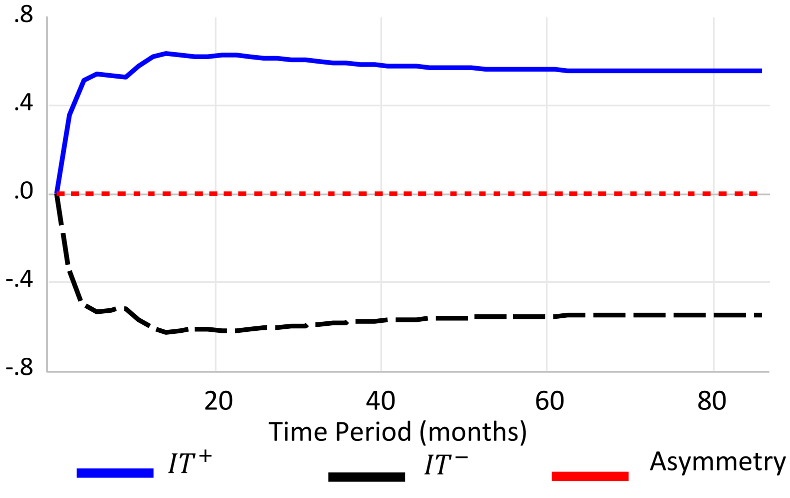


Figure 32. Dynamic Multipliers: Spain – Italy (Italy forcing)

Figure 33 presents the results from the CUSUM of squares test which is used to estimate the stability of the selected NARDL model (d), with symmetry in both the long and the short run. Since the CUSUM of squares test (blue line) does not exceed the critical bounds (red lines) at 5% significance level, there is no instability in the coefficients of the selected model.

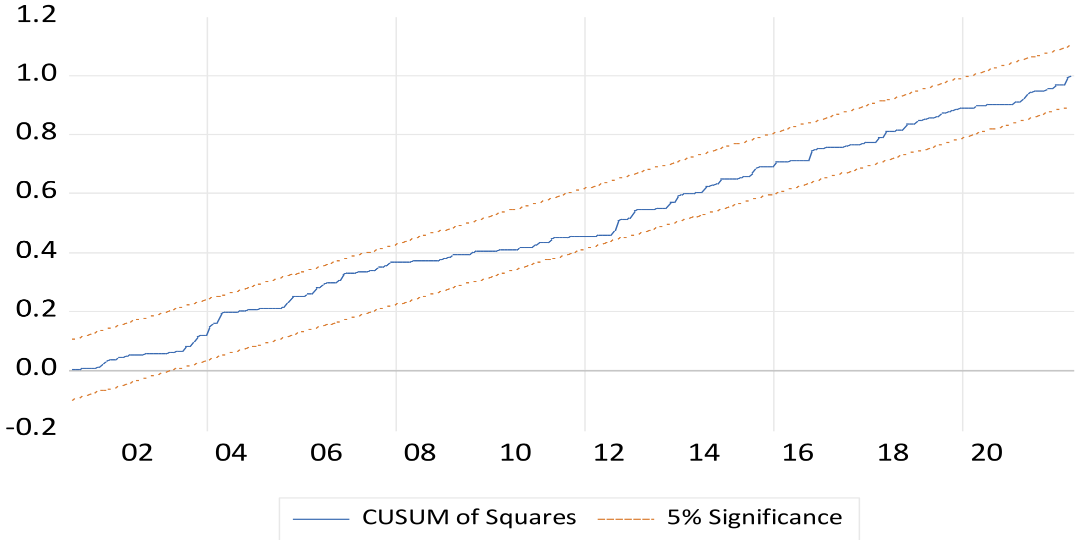


Figure 33. Cumulative sum (CUSUM) of squares test in model (d) with long-run and short-run symmetry.

Relation between Greece and Italy, with Italy forcing

Finally, the relation between GR and IT with Italy forcing is examined using the NARDL model. Initially, this is tested through model (e) with asymmetry in the long run and the short run and the results show that there is cointegration (*Table 35*). Specifically, the $\mathrm{F}_{\mathrm{PSS}}$ statistic is 5.367, and exceeds the upper bound critical value, whereas the t_{BDM} statistic is equal to -3.956 and is smaller than the upper bound critical value, further indicating the presence of cointegration.

Table 35. Bounds testing for asymmetric cointegration

Statistics	GR - IT (IT forcing)	
	NARDL model with LR & SR asymmetry (e)	NARDL model with LR symmetry & SR asymmetry (f)
F_{PSS}	5.367*	7.071**
t_{BDM}	-3.956***	-3.736**

Notes:
***, ** and * denote the rejection of the null hypothesis of no cointegration at significance levels 1, 5 and 10%, respectively.
The tests have been performed using code provided by Sunder and Greenwood-Nimmo in Stata and Eviews, V12.
For *k*=1, the critical value bounds at significance levels 1, 5, and 10% for F_{PSS} statistic are: 6.84 to 7.84, 4.94 to 5.73, and 4.04 to 4.78, respectively.
For *k*=1, the critical value bounds at significance levels 1, 5, and 10% for t_{BDM} statistic are: -3.42 to -3.82, -2.86 to -3.22, and -2.57 to -2.91 respectively.
The critical values were provided by Pesaran *et al.* (1999).

As a next step, the null hypothesis of symmetry in the long and short run is tested. According to the results on *Table 36*, W_{LR} is 1.972 with p-value 0.161 and W_{SR} is 4.392 with p-value 0.037. While the null hypothesis of symmetry cannot be rejected in the long run, it cannot be supported in the short run. Thus, this suggests that there is symmetry in the long run and asymmetry in the short run.

Table 36. Long-run and short-run symmetry tests

Statistics	GR - IT (IT forcing)	
	NARDL model with LR & SR asymmetry (e)	NARDL model with LR symmetry & SR asymmetry (f)
W_{LR}	1.972 (0.161)	–
W_{SR}	4.392 ** (0.037)	5.163** (0.023)

Notes:
***, ** and * denote the rejection of the null hypothesis of symmetry at significance levels 1, 5 and 10%, respectively.
The tests have been performed using code provided by Sunder and Greenwood-Nimmo in Stata and Eviews, V12.
W_{LR} denotes the Wald test for the null hypothesis of long-run symmetry.
W_{SR} denotes the Wald test for the null hypothesis of short-run symmetry.
In brackets, the p-values are presented.

Therefore, the NARDL model is re-estimated with model (f) with long-run symmetry and short-run asymmetry. Model (f) agrees with the results from model (e) in terms of cointegration. In particular, the F_{PSS} statistic equals 7.071 and t_{BDM} statistic is -3.736, which indicate the existence of cointegration between GR and IT with IT forcing. Since symmetry has been found in the long run, only short-run asymmetry is re-estimated with model (f). W_{SR} equals to 5.163 with p-value (0.023), indicating that the null hypothesis of symmetry in the short run can be rejected, therefore there is asymmetry in the short run.

Table 37 shows the long-run coefficient and the results of price transmission elasticity. According to the long-run coefficient, 1% increase in wholesale prices of EVOO in IT causes an increase of 0.598% in the GR prices. In previous stages of the NARDL estimation, symmetry was confirmed in the long run suggesting that unitary elasticity can be tested for the purposes of examining the LOP. Results from Wald test show that the Wstat equals to 13.144 with p-value 0.000, indicating that there is no unitary elasticity in this pair, thus the LOP cannot be empirically tested. However, to ensure that these results are valid, a Wald test for the LOP is carried out (μ=0), further confirming that the strong version of the LOP does not hold.

Table 37. Long-term coefficient and price transmission elasticity

Greece - Italy (IT effect)	
βIT,GR	0.598***
Wstat	13.144 (0.000)
μ=0	5.603 (0.018)

Notes:
β denotes the long-run coefficient.
The tests have been performed using code provided by Sunder and Greenwood-Nimmo in Stata and Eviews, V12.
Wstat denotes the Wald statistic for unitary elasticity.
μ=0 denotes the null hypothesis for the strong version of the law of one price.
In brackets (), the p-values are presented.

Table 38 shows the estimation of the NARDL model (f). The short-term coefficients suggest that negative shocks in the wholesale prices of EVOO in IT are transmitted with a lower intensity to the wholesale prices of EVOO in GR compared to positive shocks.
In addition, it presents some statistics and the outcomes from diagnostic tests which have been performed to examine the suitability and accuracy of the model. Particularly, R^2 equals 0.307 meaning that the variations in the prices of IT indicate the variations in the prices of GR at 30.7%. Furthermore, the diagnostic tests reveal no ARCH effects or serial correlation.

Table 38. NARDL model (f) estimation

Greece - Italy (IT effect)		
Variable	**Coefficient**	**SE**
Constant	0.150	0.063
LNGRt-1	-0.071***	0.019
LNITt-1	0.042***	0.013
ΔLNIT+	0.345***	0.064
ΔLNIT-	0.309***	0.077
ΔLNIT-t-11	0.174**	0.076
ΔLNGRt-1	0.239***	0.054
Statistics & Diagnostic tests		
R^2		0.307
R^2adj		0.290
Serial Correlation – SC		10.360 (0.584)
Heteroskedasticity - ARCH		13.251 (0.351)

Notes:
***, ** and * denote the rejection of the null hypothesis of symmetry at significance levels 1, 5 and 10%, respectively.
The tests have been performed using code provided by Sunder and Greenwood-Nimmo in Stata and Eviews, V12.
Symbols + and – denote the positive and negative deviations from equilibrium.

According to *Figure 34*, which shows the dynamic multipliers for price pair GR – IT with IT forcing, the red line is suggesting that it takes approximately 4 years to adjust to equilibrium.

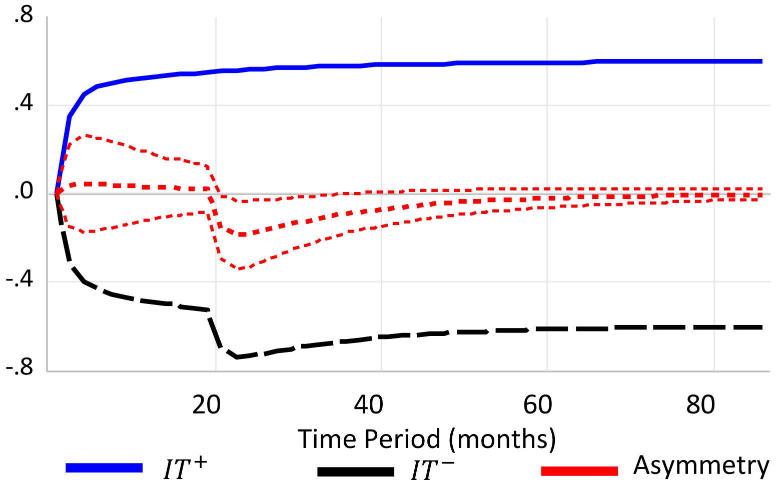


Figure 34. Dynamic Multipliers: Greece - Italy (Italy forcing)

The CUSUM of squares test is further employed to evaluate the stability of the NARDL model for the price pair GR – IT with IT forcing. Results presented in *Figure 35* show that the blue line, which demonstrates the CUSUM of squares test, does not fall outside of the red lines, which represent the critical bounds at 5% significance level. This suggests that the coefficients of the selected model are stable.

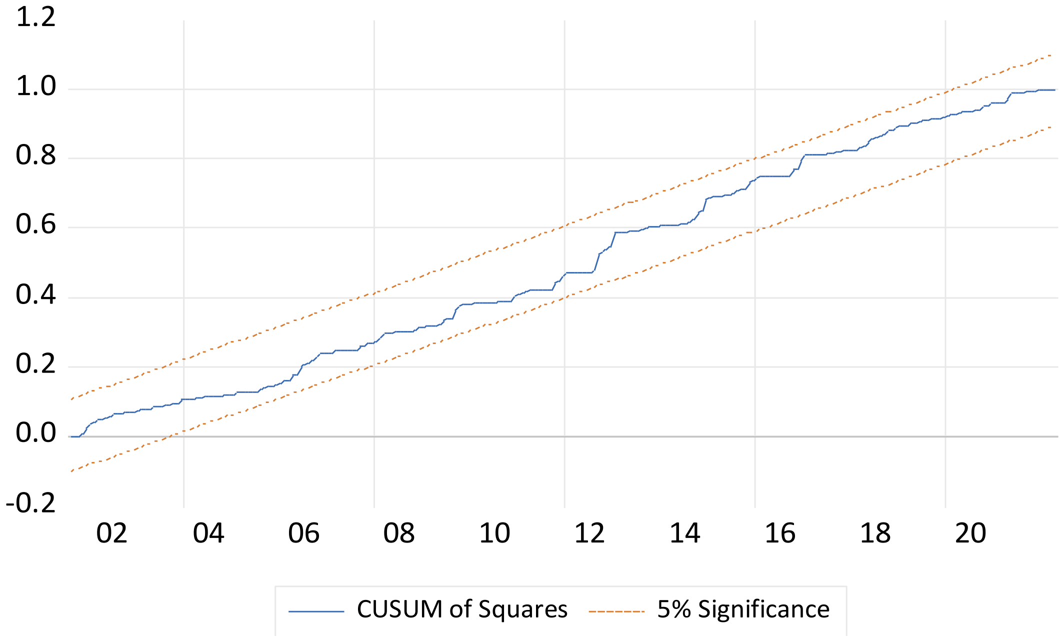


Figure 35. Cumulative sum (CUSUM) of squares test in model (f) with long-run symmetry and short-run asymmetry

4.5.5 Summary of Findings - EVOO

This section aims to examine the price relationships among the three primary producer countries of extra virgin olive oil in the European Union (EU). Specifically, the objectives are to identify the dominant market that influences price formation, to comprehend the interdependence of prices across the markets, and to discern the pattern in which price transmission occurs among the analysed markets.

The bootstrap causality test revealed that the central EVOO market in the EU is Italy (IT). Specifically, changes in the EVOO prices cause price changes in both Spain (ES) and Greece (GR), whereas ES leads prices in GR only. Emmanoulides *et al.* (2014) and Panagiotou and Stavrakoudis (2021) reached similar conclusions determining IT as the central market due to its role as the main importer of EVOO in the EU. This is consistent with Goodwin and Piggott (2001) who suggested that the central market can be selected based on certain characteristics in terms of volume, e.g. the main exporter or the main importer or the main consumer. In addition, EVOO accounted for 61% of EU imports of olive oil in 2020 (CBI, 2022) and for about 2/3 of Italian olive oil production (Carbone *et al.*, 2018). This approach was also adopted by Serra *et al.* (2006b) in poultry markets and Gervais (2011) for pork markets.

Although, the null hypothesis of no causality is rejected for pair IT-ES, albeit at a significance level of 10%, which warrants additional testing. Therefore, the Diks and Panchenko (2006) test revealed similar results for pairs ES-GR and IT-GR, while it showed no causal relationship between IT-ES.

This is also found in terms of long-run relationships; two of the three price pairs that were investigated; GR-ES and GR-IT, exhibit stable long-run relations, whereas the empirical analysis showed weak long-run relation between ES and IT. Prices in GR and ES appear to comove which can be attributed to the fact that both of these countries are the most integral providers of EVOO in the IT bottling industry (Panagiotou and Stavrakoudis, 2021). In the case of GR and IT, the strength in their relationship is also based on trade terms, whereby the majority of GR olive oil production is EVOO (82%) and most of these quantities (88%) are exported to IT (Panagiotou, 2015). As far as the weak relationship between IT and ES is concerned, this finding agrees with Emmanouilides *et al.* (2014) who also found that the strength of price dependence between IT and ES is not very high. They explained this, to an extent, by the presence of transaction costs in international trade.

Mixed results are found in relation to the pattern of price transmission in the EVOO markets, since one of the price pairs demonstrate symmetry whereas the other two pairs confirm the presence of asymmetries in these markets. Specifically, all price pairs are characterised by symmetry in the long-run indicating a stable relationship, however, asymmetry is found between GR-ES and GR-IT in the short run. For the pair ES-IT, symmetry is confirmed in both the long and the short run. This may be explained by the fact that the majority of Italy’s EVOO imports derive from ES (Statista, 2021). Furthermore, the presence of asymmetries in the cases of GR-ES and GR-IT can be attributed to longer physical distance between GR-ES (Grigoriadis *et al.*, 2016) and to a uni-directional trade relationship between GR and IT, whereby GR consistently acts as the net exporter and IT as the net importer (Goodwin and Piggott, 2011; Emmanouilides and Fousekis, 2012). Similar results in terms of the physical distance contributing to asymmetric price transmission were found by Fousekis (2015) in the EU pork market as well as Emmanouilides *et al.* (2014) who concluded to a unilateral relationship between GR in the cases of EVOO and lampante olive oil.

In both cases where asymmetries are confirmed in the short-run relation between the countries, positive shocks are found to be transmitted with a higher intensity compared to negative price shocks. This is true in the cases of GR-ES and GR-IT. Therefore, producers of EVOO in GR are more likely to benefit by price increases in EVOO prices in ES and IT, than be “harmed” by price decreases. However, consumers in GR are more likely to be “harmed” by increases in the EVOO prices in ES and IT than benefit by price decreases. Similar results were confirmed in skimmed milk powder markets between the USA, EU, and Oceania (Fousekis and Trachanas, 2016). In addition, results in the present study revealed that it takes approximately 2 years and 10 months for the GR-ES relationship to return to equilibrium following a shock in the prices of ES, whereas it takes longer to adjust in the case of GR-IT following a price shock in IT. Although asymmetries were established in the short-run relationship between the majority of the price pairs, symmetry was confirmed in the case of ES-IT (with IT forcing). Therefore, increases and decreases in the prices of IT are transmitted with the same speed to ES, indicating that no country loses out in this relationship.

Moreover, price dependence appears to be stronger in the case of GR and ES, whereby 1% increase in EVOO wholesale prices in ES causes an increase of 0.853% in the GR prices. In the case of the price pairs IT-GR and IT-ES, 1% increase in prices in IT causes an increase of 0.598% and 0.557% in the prices of GR and ES, respectively.

Overall, the olive oil market in the EU, when considering the EVOO quality, appears to be inefficient. According to the empirical analysis, the pre-requisites to enable the LOP to be tested, were not met, i.e. no presence of unitary elasticity in the examined pairs. A second test to ensure the validity of this outcome also confirmed that the LOP does not hold in its strong version in any of these markets, indicating that the EVOO market is characterised by inefficiencies.

Chapter 5 Conclusions, Policy Implications and Further Research

5.1 Conclusions

This study contributes to new knowledge by examining price linkages in EU principal Olive oil markets using a mixed method approach through a systematic map and econometric techniques to analyse price relations.

In particular, the purpose of the systematic map is to collate evidence of price dependence and the pattern of price transmission in EU edible oil markets with the ultimate purpose to further confirm the research gap in the literature for studies that investigate the EU olive oil markets in particular.

The systematic map confirmed the gap in the literature for studies that examine the price transmission process in EU olive oil markets, since only 3 out of 15 studies in the sample focused on olive oil markets, while the majority of the studies were related to rapeseed oil. A correlation was revealed between the concentrated interest in this type of edible oil, especially after 2010 and the introduction of policies that aimed to promote biofuels usage.

The analysis of the final sample of studies supported that edible oil markets in the EU are well integrated and there is price dependence between EU edible oil markets and energy markets, with a unidirectional causal relationship whereby energy markets lead prices in EU edible oil markets. Asymmetric price transmission is confirmed in these markets with market power and policy intervention identified as the most common causes of asymmetries. In terms of EU olive oil markets in particular, there were mixed results about the integration of these markets, while asymmetries were also confirmed in the other EU edible oil markets.

The empirical analysis of this study involved the econometric investigation of price relationships between the major EU olive oil markets, namely Spain, Italy, and Greece. In contrast with existing literature, this study examined long-run price relations under a single system and accounting for breaks and nonlinearities through the NARDL technique, as well as employing the nonlinear Diks and Panchenko causality test. Furthermore, more recent data were used in this study to further understand the potential impact of the last CAP reform.

This was completed in two separate sub-sections; one for extra virgin olive oil and one for virgin olive oil. These are the two highest qualities of olive oil and due to their health benefits and consumer trend towards healthier diets and lifestyles, the demand for these types of olive oil is expected to rise. Therefore, it is of great importance to evaluate the effectiveness of these markets in order to achieve equal distribution of welfare for farmers and consumers. While exploring potential structural breaks in the price series, both products exhibited price shocks in specific time periods. However, more structural breaks are identified in the case of extra virgin olive oil, which means that it may be more difficult to forecast future price points. In the majority of cases, the structural breaks are a result of fluctuations in olive oil production due to environmental factors such as extreme weather conditions and crop diseases.

In terms of market integration, the olive oil markets in EU are found to be cointegrated with a strong long-run relationship between the key players. However, this depends on the quality of olive oil and the degree of integration between the countries. In particular, in the case of virgin olive oil, the strongest cointegration relationship is exhibited between Italy and Greece which may be explained by the closer geographical proximity and more intense trading relationship between the two countries. These results agree with the findings in extra virgin olive oil markets which also reveal a weaker cointegration relationship between Italy and Spain. The weaker long-run relationship between Italy and Spain can be attributed to the fact that the quality of olive oil that is mainly traded between these countries is virgin olive oil and not extra virgin olive oil, hence the lower degree of cointegration found in this price pair.

One of the main differences between virgin and extra virgin olive oil markets revealed by the findings of this study is related to the role the principal markets play in price formation of olive oil, i.e., the country that acts as the price leader and the countries that act as the price followers. While in the case of virgin olive oil Spain is identified as the central market, Italy is found to be the central market in the case of extra virgin olive oil. Specifically, Spain is found to be the price leader in the virgin olive oil markets since it causes prices in both Greece and Italy, whereas Italy only causes Greece but not Spain, and Greece is found to have no effect on neither Italy nor Spain. Spain is the largest producer and exporter of virgin olive oil which is the reason it leads price formation in Greece and Italy. Whereas, in the case of extra virgin olive oil the central market is found to be the largest importer of extra virgin olive oil, i.e., Italy. Noteworthy is the finding of no causal relationship found between Italy and Spain which is in line with the weak cointegrating relationship that was confirmed earlier in the study. This is attributed to extra virgin olive oil not being the number one olive oil quality imported/exported between Italy and Spain.

To further understand the effect of each country to the other, the long-run coefficients were estimated which revealed higher price dependence between Italy and Greece for virgin olive oil and Spain and Greece for extra virgin olive oil. This is deduced since a 1% increase in the prices of Italian virgin olive oil causes a higher price increase in prices in Greece (0.96%) compared to the effect of 1% increase in prices in Spain, which cause

0.86% and 0.81% prices increases in Greek and Italian virgin olive oil markets, respectively. However, when considering price dependence in extra virgin olive oil markets, the highest degree of price dependence is confirmed between Spain and Greece. Here a 1% increase in the prices of Spain's prices cause a 0.83% increase in Greece's prices. In addition, while Italy is found to lead prices in both Spain and Greece, 1% increase in the prices of Italian extra virgin olive oil cause a lower percentage increase in the prices in Spain (0.55%) and Greece (0.59%), confirming a lower degree of price dependence in these price pairs.

In terms of the pattern of price transmission in olive oil markets in general, the conclusions are mixed. In particular, in the majority of the price pairs for virgin olive oil (Spain-Greece and Spain-Italy), the pattern is found to be asymmetric since negative shocks in the prices of virgin olive oil in Spain are transmitted with higher magnitude to prices in Greece and Italy than positive price shocks. This means that consumers if virgin olive oil in Greece and Italy are more likely to benefit from negative shocks (price reductions in Spain), than it is to be "harmed" by price increases in Spain. Conversely, virgin olive oil producers in Greece and Italy are more likely to be "harmed" by price reductions in Spain than benefit from price increases in Spain. Asymmetry is also confirmed when considering the adjustment process to long-run equilibrium following a shock in the prices for the pairs Greece-Spain and Italy Spain. Greece is found to respond slower to positive price shocks in both Spain and Italy compared to negative price shocks. However, Greece requires less time to adjust to positive deviations in Italy than in Spain, which may be due to the higher level of intensity in the trade flow between Italy and Greece than Spain and Greece. Italy also responds quicker to negative price shocks in Spain than positive price shocks. This may be due to the fact that the longer Greece and Italy take to respond to price reductions in Spain, the higher the risk of losing their market share to Spain. These findings indicate that the virgin olive oil markets overall are characterised by asymmetries, however, one of the price pairs is found to follow a symmetric price transmission process. Positive and negative deviations from long-term equilibrium are transmitted with the same magnitude between Italy and Greece. Since symmetry is found only in the case of Italy and Greece, the LOP is rejected by definition for price pairs Spain-Greece and Spain-Italy. The LOP is found to hold in its strong version between Italy and Greece, which indicates a high level of efficiency in these markets.

Findings are slightly different when examining extra virgin olive oil markets since symmetry is confirmed in all examined pairs in the long run, while asymmetries are only identified between Spain and Greece, and Italy and Greece in the short run. In the case of asymmetries in extra virgin olive oil markets, these relate to positive deviations in the prices of extra virgin olive oil in Spain and Italy being transmitted with higher magnitude to prices in Greece compared to negative deviations. In terms of the validity of the LOP in

EU extra virgin olive oil markets, the law is rejected by definition for price pairs Spain-Greece and Italy-Greece since asymmetries are identified in their relationship. In the case of Italy and Spain, while symmetry is confirmed which is one of the necessary pre-requisites to allow for the examination of the LOP, the second pre-requisite is not fulfilled since unitary elasticity is not confirmed in this price pair. Therefore, the LOP cannot be tested, and the strong version of the law does not hold in extra virgin olive oil markets in the EU, suggesting inefficiency.

Overall, findings suggest that in terms of spatial price transmission in olive oil markets in the EU, the principal olive oil markets are well-integrated since wholesale prices comove. However, asymmetries are present in the price transmission and adjustment to equilibrium processes for some of the examined price pairs. Therefore, prices are not fully transmitted between the markets which are closely related to production and trade-related factors and transaction costs, primarily. Also, the virgin olive oil markets appear to be slightly more efficient than the extra virgin olive oil markets in the EU. Higher-quality products would be expected to drive prices and, in a sense, markets to be more integrated (Swinnen and Vandeplas, 2014; Surathkal et al., 2014;). In this case, though, results imply otherwise. However, this argument should be treated with caution since markets have been examined separately and cannot be directly compared.

Despite that, evidence support that higher volumes of virgin olive oil have been traded within these markets over the examined years and for longer compared to extra virgin olive oil, since the increased interest and consumer preference for the quality of extra virgin olive oil is relatively more recent. This may indicate that EU markets are more experienced and had more time to solidify trading, communication, and adjustment practices in relation to virgin olive oil quality than extra virgin quality.

Nevertheless, imperfections and price dispersions still exist in both olive oil quality markets which calls for policy reforms to address market inefficiencies and strengthen the EU olive oil markets.

5.2 Policy Implications and Recommendations

The degree of market integration and price transmission are crucial metrics for the monitoring, examination and analysis of the structure and functionality of markets. The analysis of spatial price transmission particularly, provide valuable insight to understand the competitive relationships between geographically-separated markets and is a very powerful tool for policymakers when making decisions to support and strengthen competition in the sector.

The findings of asymmetric price transmission suggest the need for policy reforms to address any inefficiencies that were identified in the markets. Asymmetries indicate inequality in welfare distribution for some of the stakeholders. For example, the olive oil market in the EU is an oligopolistic market where market power is exercised by a few bottling corporations leading to high market concentration. This can cause welfare losses for farmers. This study proposes research and active monitoring-intervention in the olive oil markets to be exercised by the European Commission or other EU agents. This will ensure that there is transparency and immediacy of information among all stakeholders, so that farmers can also benefit from potential price increases. This can be achieved through the use of data analytics platforms which will collect, analyse and visualise historical data as well as economic modelling software to promote forecasting which in turn will help for better planning. In practice, the European Commission could standardise the data collection requirements and provide access to a single recording and monitoring system to each country-member, which will strengthen the quality and accuracy of the data. In addition, the price transmission pattern and market integration is affected primarily by the performance of the supply chain within each country. Therefore, data collected should include price points across all the supply chain stakeholders and that data to be accessible from the EC's single database. Moreover, through supply chain monitoring using real-time tracking of olive oil production and trade, market transparency and integrity will be strengthened. Furthermore, precision agriculture tools, i.e. satellite and remote sensing could help address quality and safety concerns in relation to the olive trees, whereas blockchain and traceability solutions will monitor the olive oil production process further enhancing consumer trust.

In addition, transaction costs are identified as one of the most important causes of asymmetry in this study, which has also been identified by other researchers too. While transactions costs are found to influence the price transmission process in EU olive oil markets, there is lack of information on these as there is no consistent way of capturing and recording this information. Therefore, this study proposes the development of an electronic platform where the transaction costs are periodically recorded. This platform can be updated by each country on a daily/weekly/monthly basis along with the recording of price points and be available through the European Commission database. This would allow for transparency of this information as they can be categorised to wholesale and retail levels to achieve complete information, thus strengthening market integration. This will also prevent countries, to an extent, from exploiting this situation and exercising market power.

As an extension of this, the electronic platform could be integrated with other functions such as also act as a stakeholder engagement platform facilitating communication and collaboration between different markets. This integrated platform could ultimately become a digital gate, i.e. an online portal, for stakeholders to access in their own time and will provide them with access to updates, guidance, training, and a communication channel to share best practice. This would contribute to farmers' continued professional development. Furthermore, considering the importance of oils in general for the EU and in light of the recent events of the oil crisis due to the political conflicts that are currently unfolding between Ukraine and Russia, it is crucial to review policy interventions in other edible oil markets and aim to achieve consistency across other types of edible oils to strengthen even further market integration. This suggestion derives from the notion that policy measures that are applied to one type of oil market can also affect other oil markets (Karikallio, 2015).

Finally, based on the results of this study a threshold has been determined to indicate the point that triggers the adjustment process between the price pairs. Therefore, it is recommended that policy measures are introduced to define the equilibrium point and threshold prices for each country to achieve and maintain market integration. Close price monitoring and policy measures that are based on threshold value analysis in these markets, can help encourage healthy competition, thus strengthening the markets.

5.3 Study Limitations and Further Research

While the findings of this study offer significant insight to price linkages in the major EU olive oil markets, there are some limitations. To start with, the systematic map undertaken provided evidence regarding the price transmission patterns in the EU edible oil markets and enabled the identification and further establishment of the research gap in relation to studies examining price linkages in the EU olive oil market. However, further research should be conducted by examining edible oil markets on a global level, or through a systematic review to further synthesize and analyse data. In addition, the systematic map was limited to studies published in English language. Therefore, the same study can be undertaken expanding the search to include studies in other languages such as Spanish, Italian, and Greek.

With regards to the second empirical chapter of this study, the data utilised are wholesale monthly prices for olive oil in Spain, Italy, and Greece from January 1993 to April 2022. Therefore, data outside of this date range are excluded from this analysis and thus potential significant events and findings before January 1993 and after April 2022 have not been considered. A longer period of data could be employed, or even employ a higher frequency of data (e.g. daily price data) to more closely examine price volatility in EU olive oil markets.

In addition, in the present study non-linearities have been considered due to transaction costs in spatial price transmission. Therefore, the NARDL test was performed which assumes the threshold is equal to 0. However, threshold could be determined endogenously from the data as in the case of TAR and MTAR models.

Also, this study is based on the examination of virgin and extra virgin olive oil qualities and does not consider other qualities of olive oil such as lampante olive oil. Therefore, the findings of this study may not be representative of the EU olive oil market in general, just virgin, and extra virgin olive oil.

In addition, while Spain, Italy, and Greece are the principal olive oil producers in the EU, they are not the only producer countries in the EU or internationally. Therefore, this can be considered as a limitation since information and data from other notable producer countries, such as Portugal, France, Tunisia, are not considered in this study.

Finally, the analysis of price linkages is based on spatial price transmission and does not consider any information or factors that may influence vertical or horizontal price transmission. Therefore, further research is proposed to analyse the three countries on a vertical level to determine whether there are other factors that need to be considered in future policy-making, through examining vertical price transmission and testing for asymmetries. Furthermore, the same study could be expanded by including more countries such as Portugal and France or examine price linkages in olive oil markets on a Pan-European level, or price relationships between European and international markets.

Another recommendation for further research could be to conduct the research to compare price relations between different olive oil qualities (i.e. extra virgin, virgin and lampante olive oils) to understand whether olive oil quality, as a type of product characteristic, can affect the price transmission process, as suggested by literature.

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APPENDIX A

DATABASE SEARCH SUMMARY – LIST OF SEARCH STRINGS USED

No	DATABASE	SEARCH STRING USED	FILTERS APPLIED	LIMITATIONS (if any)	RESULTS	DUPLICATES	RESULTS AFTER DUPLICATES	Notes	Search date
1	**Science Direct**	Combination of search strings due to database limitations.	Date: 1993-2020	No more than 8 Boolean connectors Wildcards not supported Only up to 6,000 results available to view or download	2652	779	1873	Science Direct does not allow the user to view or access results over 6,000. A combination of search strings with up to 8 Boolean connectors had to be used and the keyword "LOOP" was removed as the number of results with this keyword was unmanageable as the database included results that used "LOOP" with other definitions other than the abbreviation of "Law of One Price" that was intended.	25/05/2020
2	**Web of Science**	("price transm*" OR "price relat*" OR "price co-movement*" OR "price comovement*" OR "price co movement*" OR "price independenc*" OR "price inter-dependenc*" OR "price interdependenc*" OR "price dispersion*" OR "price volatilit*" OR "price regime*" OR "price inter-relationship*" OR "price interrelationship*" OR "price inter-relation*" OR "price interrelation*" OR "price pass-through" OR "price pass through" OR "price integration" OR "price link*" OR "price determin*" OR "price spillover" OR "price symmetr*" OR "price asymmetr*" OR "price shock*" OR "market integration" OR "law of one price" OR "LOP" OR "LOOP" OR "price signal*" OR "price pattern*" OR "price convergence" OR "spillover effect*" OR "symmetric price transmission*" OR "asymmetric price transmission*") AND ("olive" OR "olives" OR "edible oil" OR "vegetal product" OR "vegetal products" OR "extra virgin olive oil" OR "lampante olive oil" OR "virgin olive oil" OR "crude olive-pomace oil" OR "olive-pomace oil" OR "refined olive oil" OR "refined olive-pomace oil" OR "seasame oil" OR "acai oil" OR "almond oil" OR "amaranth oil" OR "apple seed oil" OR "apricot oil" OR "argan oil" OR "avocado oil" OR "babassu oil" OR "beech nut oil" OR "ben oil" OR "black seed oil" OR "blackcurrant seed oil" OR "borage seed oil" OR "borneo tallow nut oil" OR "brazil nut oil" OR "butternut squash seed oil" OR "canola oil" OR "carob pod oil" OR "cashew oil" OR "cocklebur oil" OR "cocoa butter" OR "coconut oil" OR "cohune oil" OR "coriander seed oil" OR "corn oil" OR "cottonseed oil" OR "dammr oil" OR "date seed oil" OR "grape seed oil" OR "grapefruit seed oil" OR "hazelnut oil" OR "hemp oil" OR "kapok seed oil" OR "kenaf seed oil" OR "lallemantia oil" OR "lemon oil" OR "linseed oil" OR "macademia oil" OR "mafura oil" OR "marula oil" OR "meadowfoam seed oil" OR "mongongo nut oil" OR "mustard oil" OR "niger seed oil" OR "nutmeg butter" OR "okra seed oil" OR "orange oil" OR "palm oil" OR "papaya seed oil" OR "peanut oil" OR "pecan oil" OR "pequi oil" OR "perlla seed oil" OR "persimmon seed oil" OR "pili nut oil" OR "prime nut" OR "pistachio oil" OR "pomegranate seed oil" OR "poppyseed oil" OR "pracaxil oil" OR "prune kernel oil" OR "pumpkin seed oil" OR "quinoa oil" OR "ramtil oil" OR "rapeseed oil" OR "rice bran oil" OR "royle oil" OR "sacha inchi oil" OR "safflower oil" OR "sapote oil" OR "seje oil" OR "shea butter" OR "soyben oil" OR "stillingia oil" OR "sunflower oil" OR "tall oil" OR "taramira oil" OR "tea seed oil" OR "thristle oil" OR "tigernut oil" OR "tobacco seed oil" OR "tung oil" OR "vernonie oil" OR "walnut oil" OR "watermelon seed oil" OR "wheat germ oil")	Date: 1993-2020	None	261	0	261		18/05/2020
3	**AgEcon**	("price transmission" OR "price transmitted" OR "price relation" OR "price relations" OR "price co-movement" OR "price co-movements" OR "price comovement" OR "price independence" OR "price independencies" OR "price inter-dependence" OR "price inter-dependencies" OR "price interdependence" OR "price interdependencies" OR "price dispersion" OR "price dispersions" OR "price volatility" OR "price regime" OR "price regimes" OR "price inter-relationship" OR "price inter-relationships" OR "price interrelationship" OR "price interrelationships" OR "price inter-relation" OR "price inter-relations" OR "price interrelation" OR "price interrelations" OR "price pass-through" OR "price pass through" OR "price integration" OR "price link" OR "price links" OR "price linkage" OR "price linkages" OR "price determinant" OR "price determinants" OR "price determination" OR "price spillover" OR "price symmetry" OR "price symmetries" OR "price asymmetry" OR "price asymmetries" OR "price shock" OR "price shocks" OR "price convergence" OR "market integration" OR "law of one price" OR "LOP" OR "LOOP" OR "price signal" OR "price signals" OR "price pattern" OR "price patterns" OR "spillover effect") AND ("olive" OR "olives" OR "edible oil" OR "vegetal product" OR "vegetal products" OR "extra virgin olive oil" OR "lampante olive oil" OR "virgin olive oil" OR "crude olive-pomace oil" OR "olive-pomace oil" OR "refined olive oil" OR "refined olive-pomace oil" OR "seasame oil" OR "acai oil" OR "almond oil" OR "amaranth oil" OR "apple seed oil" OR "apricot oil" OR "argan oil" OR "avocado oil" OR "babassu oil" OR "beech nut oil" OR "ben oil" OR "black seed oil" OR "blackcurrant seed oil" OR "borage seed oil" OR "borneo tallow nut oil" OR "brazil nut oil" OR "butternut squash seed oil" OR "canola oil" OR "carob pod oil" OR "cashew oil" OR "cocklebur oil" OR "cocoa butter" OR "coconut oil" OR "cohune oil" OR "coriander seed oil" OR "corn oil" OR "cottonseed oil" OR "dammr oil" OR "date seed oil" OR "grape seed oil" OR "grapefruit seed oil" OR "hazelnut oil" OR "hemp oil" OR "kapok seed oil" OR "kenaf seed oil" OR "lallemantia oil" OR "lemon oil" OR "linseed oil" OR "macademia oil" OR "mafura oil" OR "marula oil" OR "meadowfoam seed oil" OR "mongongo nut oil" OR "mustard oil" OR "niger seed oil" OR "nutmeg butter" OR "okra seed oil" OR "orange oil" OR "palm oil" OR "papaya seed oil" OR "peanut oil" OR "pecan oil" OR "pequi oil" OR "perlla seed oil" OR "persimmon seed oil" OR "pili nut oil" OR "prime nut" OR "pistachio oil" OR "pomegranate seed oil" OR "poppyseed oil" OR "pracaxil oil" OR "prune kernel oil" OR "pumpkin seed oil" OR "quinoa oil" OR "ramtil oil" OR "rapeseed oil" OR "rice bran oil" OR "royle oil" OR "sacha inchi oil" OR "safflower oil" OR "sapote oil" OR "seje oil" OR "shea butter" OR "soyben oil" OR "stillingia oil" OR "sunflower oil" OR "tall oil" OR "taramira oil" OR "tea seed oil" OR "thristle oil" OR "tigernut oil" OR "tobacco seed oil" OR "tung oil" OR "vernonie oil" OR "walnut oil" OR "watermelon seed oil" OR "wheat germ oil")	Date: 1993-2020	None	26	0	26		16/05/2020

4	**Food Science Source**	("price transmission" OR "price transmitted" OR "price relation" OR "price relations" OR "price co-movement" OR "price co-movements" OR "price comovement" OR "price independence" OR "price independencies" OR "price inter-dependence" OR "price inter-dependencies" OR "price interdependence" OR "price interdependencies" OR "price dispersion" OR "price dispersions" OR "price volatility" OR "price regime" OR "price regimes" OR "price inter-relationship" OR "price inter-relationships" OR "price interrelationship" OR "price interrelationships" OR "price inter-relation" OR "price inter-relations" OR "price interrelation" OR "price interrelations" OR "price pass-through" OR "price pass through" OR "price integration" OR "price link" OR "price links" OR "price linkage" OR "price linkages" OR "price determinant" OR "price determinants" OR "price determination" OR "price spillover" OR "price symmetry" OR "price symmetries" OR "price asymmetry" OR "price asymmetries" OR "price shock" OR "price shocks" OR "price convergence" OR "market integration" OR "law of one price" OR "LOP" OR "LOOP" OR "price signal" OR "price signals" OR "price pattern" OR "price patterns" OR "spillover effect") AND ("olive" OR "olives" OR "edible oil" OR "vegetal product" OR "vegetal products" OR "extra virgin olive oil" OR "lampante olive oil" OR "virgin olive oil" OR "crude olive-pomace oil" OR "olive-pomace oil" OR "refined olive oil" OR "refined olive-pomace oil" OR "seasame oil" OR "acai oil" OR "almond oil" OR "amaranth oil" OR "apple seed oil" OR "apricot oil" OR "argan oil" OR "avocado oil" OR "babassu oil" OR "beech nut oil" OR "ben oil" OR "black seed oil" OR "blackcurrant seed oil" OR "borage seed oil" OR "borneo tallow nut oil" OR "brazil nut oil" OR "butternut squash seed oil" OR "canola oil" OR "carob pod oil" OR "cashew oil" OR "cocklebur oil" OR "cocoa butter" OR "coconut oil" OR "cohune oil" OR "coriander seed oil" OR "corn oil" OR "cottonseed oil" OR "dammr oil" OR "date seed oil" OR "grape seed oil" OR "grapefruit seed oil" OR "hazelnut oil" OR "hemp oil" OR "kapok seed oil" OR "kenaf seed oil" OR "lallemantia oil" OR "lemon oil" OR "linseed oil" OR "macademia oil" OR "mafura oil" OR "marula oil" OR "meadowfoam seed oil" OR "mongongo nut oil" OR "mustard oil" OR "niger seed oil" OR "nutmeg butter" OR "okra seed oil" OR "orange oil" OR "palm oil" OR "papaya seed oil" OR "peanut oil" OR "pecan oil" OR "pequi oil" OR "perlla seed oil" OR "persimmon seed oil" OR "pili nut oil" OR "prime nut" OR "pistachio oil" OR "pomegranate seed oil" OR "poppyseed oil" OR "pracaxil oil" OR "prune kernel oil" OR "pumpkin seed oil" OR "quinoa oil" OR "ramtil oil" OR "rapeseed oil" OR "rice bran oil" OR "royle oil" OR "sacha inchi oil" OR "safflower oil" OR "sapote oil" OR "seje oil" OR "shea butter" OR "soyben oil" OR "stillingia oil" OR "sunflower oil" OR "tall oil" OR "taramira oil" OR "tea seed oil" OR "thristle oil" OR "tigernut oil" OR "tobacco seed oil" OR "tung oil" OR "vernonie oil" OR "walnut oil" OR "watermelon seed oil" OR "wheat germ oil")	Date: 1993-2020	None	28	0	28		16/05/2020
5	**CABI**	("price transmission" OR "price transmitted" OR "price relation" OR "price relations" OR "price co-movement" OR "price co-movements" OR "price comovement" OR "price independence" OR "price independencies" OR "price inter-dependence" OR "price inter-dependencies" OR "price interdependence" OR "price interdependencies" OR "price dispersion" OR "price dispersions" OR "price volatility" OR "price regime" OR "price regimes" OR "price inter-relationship" OR "price inter-relationships" OR "price interrelationship" OR "price interrelationships" OR "price inter-relation" OR "price inter-relations" OR "price interrelation" OR "price interrelations" OR "price pass-through" OR "price pass through" OR "price integration" OR "price link" OR "price links" OR "price linkage" OR "price linkages" OR "price determinant" OR "price determinants" OR "price determination" OR "price spillover" OR "price symmetry" OR "price symmetries" OR "price asymmetry" OR "price asymmetries" OR "price shock" OR "price shocks" OR "price convergence" OR "market integration" OR "law of one price" OR "LOP" OR "LOOP" OR "price signal" OR "price signals" OR "price pattern" OR "price patterns" OR "spillover effect") AND ("olive" OR "olives" OR "edible oil" OR "vegetal product" OR "vegetal products" OR "extra virgin olive oil" OR "lampante olive oil" OR "virgin olive oil" OR "crude olive-pomace oil" OR "olive-pomace oil" OR "refined olive oil" OR "refined olive-pomace oil" OR "seasame oil" OR "acai oil" OR "almond oil" OR "amaranth oil" OR "apple seed oil" OR "apricot oil" OR "argan oil" OR "avocado oil" OR "babassu oil" OR "beech nut oil" OR "ben oil" OR "black seed oil" OR "blackcurrant seed oil" OR "borage seed oil" OR "borneo tallow nut oil" OR "brazil nut oil" OR "butternut squash seed oil" OR "canola oil" OR "carob pod oil" OR "cashew oil" OR "cocklebur oil" OR "cocoa butter" OR "coconut oil" OR "cohune oil" OR "coriander seed oil" OR "corn oil" OR "cottonseed oil" OR "dammr oil" OR "date seed oil" OR "grape seed oil" OR "grapefruit seed oil" OR "hazelnut oil" OR "hemp oil" OR "kapok seed oil" OR "kenaf seed oil" OR "lallemantia oil" OR "lemon oil" OR "linseed oil" OR "macademia oil" OR "mafura oil" OR "marula oil" OR "meadowfoam seed oil" OR "mongongo nut oil" OR "mustard oil" OR "niger seed oil" OR "nutmeg butter" OR "okra seed oil" OR "orange oil" OR "palm oil" OR "papaya seed oil" OR "peanut oil" OR "pecan oil" OR "pequi oil" OR "perlla seed oil" OR "persimmon seed oil" OR "pili nut oil" OR "prime nut" OR "pistachio oil" OR "pomegranate seed oil" OR "poppyseed oil" OR "pracaxil oil" OR "prune kernel oil" OR "pumpkin seed oil" OR "quinoa oil" OR "ramtil oil" OR "rapeseed oil" OR "rice bran oil" OR "royle oil" OR "sacha inchi oil" OR "safflower oil" OR "sapote oil" OR "seje oil" OR "shea butter" OR "soyben oil" OR "stillingia oil" OR "sunflower oil" OR "tall oil" OR "taramira oil" OR "tea seed oil" OR "thristle oil" OR "tigernut oil" OR "tobacco seed oil" OR "tung oil" OR "vernonie oil" OR "walnut oil" OR "watermelon seed oil" OR "wheat germ oil")	Date: 1993-2020	None	174	0	174		16/05/2020

6	**World Bank**	("price transmission" OR "price transmitted" OR "price relation" OR "price relations" OR "price co-movement" OR "price co-movements" OR "price comovement" OR "price independence" OR "price independencies" OR "price inter-dependence" OR "price inter-dependencies" OR "price interdependence" OR "price interdependencies" OR "price dispersion" OR "price dispersions" OR "price volatility" OR "price regime" OR "price regimes" OR "price inter-relationship" OR "price inter-relationships" OR "price interrelationship" OR "price interrelationships" OR "price inter-relation" OR "price inter-relations" OR "price interrelation" OR "price interrelations" OR "price pass-through" OR "price pass through" OR "price integration" OR "price link" OR "price links" OR "price linkage" OR "price linkages" OR "price determinant" OR "price determinants" OR "price determination" OR "price spillover" OR "price symmetry" OR "price symmetries" OR "price asymmetry" OR "price asymmetries" OR "price shock" OR "price shocks" OR "price convergence" OR "market integration" OR "law of one price" OR "LOP" OR "LOOP" OR "price signal" OR "price signals" OR "price pattern" OR "price patterns" OR "spillover effect") AND ("olive" OR "olives" OR "edible oil" OR "vegetal product" OR "vegetal products" OR "extra virgin olive oil" OR "lampante olive oil" OR "virgin olive oil" OR "crude olive-pomace oil" OR "olive-pomace oil" OR "refined olive oil" OR "refined olive-pomace oil" OR "seasame oil" OR "acai oil" OR "almond oil" OR "amaranth oil" OR "apple seed oil" OR "apricot oil" OR "argan oil" OR "avocado oil" OR "babassu oil" OR "beech nut oil" OR "ben oil" OR "black seed oil" OR "blackcurrant seed oil" OR "borage seed oil" OR "borneo tallow nut oil" OR "brazil nut oil" OR "butternut squash seed oil" OR "canola oil" OR "carob pod oil" OR "cashew oil" OR "cocklebur oil" OR "cocoa butter" OR "coconut oil" OR "cohune oil" OR "coriander seed oil" OR "corn oil" OR "cottonseed oil" OR "dammr oil" OR "date seed oil" OR "grape seed oil" OR "grapefruit seed oil" OR "hazelnut oil" OR "hemp oil" OR "kapok seed oil" OR "kenaf seed oil" OR "lallemantia oil" OR "lemon oil" OR "linseed oil" OR "macademia oil" OR "mafura oil" OR "marula oil" OR "meadowfoam seed oil" OR "mongongo nut oil" OR "mustard oil" OR "niger seed oil" OR "nutmeg butter" OR "okra seed oil" OR "orange oil" OR "palm oil" OR "papaya seed oil" OR "peanut oil" OR "pecan oil" OR "pequi oil" OR "perlla seed oil" OR "persimmon seed oil" OR "pili nut oil" OR "prime nut" OR "pistachio oil" OR "pomegranate seed oil" OR "poppyseed oil" OR "pracaxil oil" OR "prune kernel oil" OR "pumpkin seed oil" OR "quinoa oil" OR "ramtil oil" OR "rapeseed oil" OR "rice bran oil" OR "royle oil" OR "sacha inchi oil" OR "safflower oil" OR "sapote oil" OR "seje oil" OR "shea butter" OR "soyben oil" OR "stillingia oil" OR "sunflower oil" OR "tall oil" OR "taramira oil" OR "tea seed oil" OR "thristle oil" OR "tigernut oil" OR "tobacco seed oil" OR "tung oil" OR "vernonie oil" OR "walnut oil" OR "watermelon seed oil" OR "wheat germ oil")	None	No filters available Results before 2000 - Error	53	0	53		24/05/2020
7	**ProQuest**	("price transm*" OR "price relat*" OR "price co-movement*" OR "price comovement*" OR "price co movement*" OR "price independenc*" OR "price inter-dependenc*" OR "price interdependenc*" OR "price dispersion*" OR "price volatilit*" OR "price regime*" OR "price inter-relationship*" OR "price interrelationship*" OR "price inter-relation*" OR "price interrelation*" OR "price pass-through" OR "price pass through" OR "price integration" OR "price link*" OR "price determin*" OR "price spillover" OR "price symmetr*" OR "price asymmetr*" OR "price shock*" OR "market integration" OR "law of one price" OR "LOP" OR "LOOP" OR "price signal*" OR "price pattern*" OR "price convergence" OR "spillover effect*" OR "symmetric price transmission*" OR "asymmetric price transmission*") AND ("olive" OR "olives" OR "edible oil" OR "vegetal product" OR "vegetal products" OR "extra virgin olive oil" OR "lampante olive oil" OR "virgin olive oil" OR "crude olive-pomace oil" OR "olive-pomace oil" OR "refined olive oil" OR "refined olive-pomace oil" OR "seasame oil" OR "acai oil" OR "almond oil" OR "amaranth oil" OR "apple seed oil" OR "apricot oil" OR "argan oil" OR "avocado oil" OR "babassu oil" OR "beech nut oil" OR "ben oil" OR "black seed oil" OR "blackcurrant seed oil" OR "borage seed oil" OR "borneo tallow nut oil" OR "brazil nut oil" OR "butternut squash seed oil" OR "canola oil" OR "carob pod oil" OR "cashew oil" OR "cocklebur oil" OR "cocoa butter" OR "coconut oil" OR "cohune oil" OR "coriander seed oil" OR "corn oil" OR "cottonseed oil" OR "dammr oil" OR "date seed oil" OR "grape seed oil" OR "grapefruit seed oil" OR "hazelnut oil" OR "hemp oil" OR "kapok seed oil" OR "kenaf seed oil" OR "lallemantia oil" OR "lemon oil" OR "linseed oil" OR "macademia oil" OR "mafura oil" OR "marula oil" OR "meadowfoam seed oil" OR "mongongo nut oil" OR "mustard oil" OR "niger seed oil" OR "nutmeg butter" OR "okra seed oil" OR "orange oil" OR "palm oil" OR "papaya seed oil" OR "peanut oil" OR "pecan oil" OR "pequi oil" OR "perlla seed oil" OR "persimmon seed oil" OR "pili nut oil" OR "prime nut" OR "pistachio oil" OR "pomegranate seed oil" OR "poppyseed oil" OR "pracaxil oil" OR "prune kernel oil" OR "pumpkin seed oil" OR "quinoa oil" OR "ramtil oil" OR "rapeseed oil" OR "rice bran oil" OR "royle oil" OR "sacha inchi oil" OR "safflower oil" OR "sapote oil" OR "seje oil" OR "shea butter" OR "soyben oil" OR "stillingia oil" OR "sunflower oil" OR "tall oil" OR "taramira oil" OR "tea seed oil" OR "thristle oil" OR "tigernut oil" OR "tobacco seed oil" OR "tung oil" OR "vernonie oil" OR "walnut oil" OR "watermelon seed oil" OR "wheat germ oil")	Date: 1993-2020	None	3084	0	3084	Dissertations/Theses	24/05/2020

8	**CAB Abstracts**	("price transmission" OR "price transmitted" OR "price relation" OR "price relations" OR "price co-movement" OR "price co-movements" OR "price comovement" OR "price independence" OR "price independencies" OR "price inter-dependence" OR "price inter-dependencies" OR "price interdependence" OR "price interdependencies" OR "price dispersion" OR "price dispersions" OR "price volatility" OR "price regime" OR "price regimes" OR "price inter-relationship" OR "price inter-relationships" OR "price interrelationship" OR "price interrelationships" OR "price inter-relation" OR "price inter-relations" OR "price interrelation" OR "price interrelations" OR "price pass-through" OR "price pass through" OR "price integration" OR "price link" OR "price links" OR "price linkage" OR "price linkages" OR "price determinant" OR "price determinants" OR "price determination" OR "price spillover" OR "price symmetry" OR "price symmetries" OR "price asymmetry" OR "price asymmetries" OR "price shock" OR "price shocks" OR "price convergence" OR "market integration" OR "law of one price" OR "LOP" OR "LOOP" OR "price signal" OR "price signals" OR "price pattern" OR "price patterns" OR "spillover effect") AND ("olive" OR "olives" OR "edible oil" OR "vegetal product" OR "vegetal products" OR "extra virgin olive oil" OR "lampante olive oil" OR "virgin olive oil" OR "crude olive-pomace oil" OR "olive-pomace oil" OR "refined olive oil" OR "refined olive-pomace oil" OR "seasame oil" OR "acai oil" OR "almond oil" OR "amaranth oil" OR "apple seed oil" OR "apricot oil" OR "argan oil" OR "avocado oil" OR "babassu oil" OR "beech nut oil" OR "ben oil" OR "black seed oil" OR "blackcurrant seed oil" OR "borage seed oil" OR "borneo tallow nut oil" OR "brazil nut oil" OR "butternut squash seed oil" OR "canola oil" OR "carob pod oil" OR "cashew oil" OR "cocklebur oil" OR "cocoa butter" OR "coconut oil" OR "cohune oil" OR "coriander seed oil" OR "corn oil" OR "cottonseed oil" OR "dammr oil" OR "date seed oil" OR "grape seed oil" OR "grapefruit seed oil" OR "hazelnut oil" OR "hemp oil" OR "kapok seed oil" OR "kenaf seed oil" OR "lallemantia oil" OR "lemon oil" OR "linseed oil" OR "macademia oil" OR "mafura oil" OR "marula oil" OR "meadowfoam seed oil" OR "mongongo nut oil" OR "mustard oil" OR "niger seed oil" OR "nutmeg butter" OR "okra seed oil" OR "orange oil" OR "palm oil" OR "papaya seed oil" OR "peanut oil" OR "pecan oil" OR "pequi oil" OR "perlla seed oil" OR "persimmon seed oil" OR "pili nut oil" OR "prime nut" OR "pistachio oil" OR "pomegranate seed oil" OR "poppyseed oil" OR "pracaxil oil" OR "prune kernel oil" OR "pumpkin seed oil" OR "quinoa oil" OR "ramtil oil" OR "rapeseed oil" OR "rice bran oil" OR "royle oil" OR "sacha inchi oil" OR "safflower oil" OR "sapote oil" OR "seje oil" OR "shea butter" OR "soyben oil" OR "stillingia oil" OR "sunflower oil" OR "tall oil" OR "taramira oil" OR "tea seed oil" OR "thristle oil" OR "tigernut oil" OR "tobacco seed oil" OR "tung oil" OR "vernonie oil" OR "walnut oil" OR "watermelon seed oil" OR "wheat germ oil")	Date: 1993-2020	None	145	0	145		16/05/2020
9	**AGRIS**	Combination of search strings due to database limitations.	Date: 1993-2020	Multilingual search	223	11	212		24/05/2020
10	**EMERALD**	("price transm*" OR "price relat*" OR "price co-movement*" OR "price comovement*" OR "price co movement*" OR "price independenc*" OR "price inter-dependenc*" OR "price interdependenc*" OR "price dispersion*" OR "price volatilit*" OR "price regime*" OR "price inter-relationship*" OR "price interrelationship*" OR "price inter-relation*" OR "price interrelation*" OR "price pass-through" OR "price pass through" OR "price integration" OR "price link*" OR "price determin*" OR "price spillover" OR "price symmetr*" OR "price asymmetr*" OR "price shock*" OR "market integration" OR "law of one price" OR "LOP" OR "LOOP" OR "price signal*" OR "price pattern*" OR "price convergence" OR "spillover effect*" OR "symmetric price transmission*" OR "asymmetric price transmission*") AND ("olive" OR "olives" OR "edible oil" OR "vegetal product" OR "vegetal products" OR "extra virgin olive oil" OR "lampante olive oil" OR "virgin olive oil" OR "crude olive-pomace oil" OR "olive-pomace oil" OR "refined olive oil" OR "refined olive-pomace oil" OR "seasame oil" OR "acai oil" OR "almond oil" OR "amaranth oil" OR "apple seed oil" OR "apricot oil" OR "argan oil" OR "avocado oil" OR "babassu oil" OR "beech nut oil" OR "ben oil" OR "black seed oil" OR "blackcurrant seed oil" OR "borage seed oil" OR "borneo tallow nut oil" OR "brazil nut oil" OR "butternut squash seed oil" OR "canola oil" OR "carob pod oil" OR "cashew oil" OR "cocklebur oil" OR "cocoa butter" OR "coconut oil" OR "cohune oil" OR "coriander seed oil" OR "corn oil" OR "cottonseed oil" OR "dammr oil" OR "date seed oil" OR "grape seed oil" OR "grapefruit seed oil" OR "hazelnut oil" OR "hemp oil" OR "kapok seed oil" OR "kenaf seed oil" OR "lallemantia oil" OR "lemon oil" OR "linseed oil" OR "macademia oil" OR "mafura oil" OR "marula oil" OR "meadowfoam seed oil" OR "mongongo nut oil" OR "mustard oil" OR "niger seed oil" OR "nutmeg butter" OR "okra seed oil" OR "orange oil" OR "palm oil" OR "papaya seed oil" OR "peanut oil" OR "pecan oil" OR "pequi oil" OR "perlla seed oil" OR "persimmon seed oil" OR "pili nut oil" OR "prime nut" OR "pistachio oil" OR "pomegranate seed oil" OR "poppyseed oil" OR "pracaxil oil" OR "prune kernel oil" OR "pumpkin seed oil" OR "quinoa oil" OR "ramtil oil" OR "rapeseed oil" OR "rice bran oil" OR "royle oil" OR "sacha inchi oil" OR "safflower oil" OR "sapote oil" OR "seje oil" OR "shea butter" OR "soyben oil" OR "stillingia oil" OR "sunflower oil" OR "tall oil" OR "taramira oil" OR "tea seed oil" OR "thristle oil" OR "tigernut oil" OR "tobacco seed oil" OR "tung oil" OR "vernonie oil" OR "walnut oil" OR "watermelon seed oil" OR "wheat germ oil")	Date: 1993-2020	No language selection	443	0	443		08/05/2020

11	**SCOPUS**	("price transm*" OR "price relat*" OR "price co-movement*" OR "price comovement*" OR "price co movement" OR "price independenc*" OR "price inter-dependenc*" OR "price interdependenc*" OR "price dispersion*" OR "price volatilit*" OR "price regime*" OR "price inter-relationship*" OR "price interrelationship*" OR "price inter-relation" OR "price interrelation*" OR "price pass-through" OR "price pass through" OR "price integration" OR "price link*" OR "price determin*" OR "price spillover" OR "price symmetr*" OR "price asymmetr*" OR "price shock*" OR "market integration" OR "law of one price" OR "LOP" OR "LOOP" OR "price signal*" OR "price pattern*" OR "price convergence" OR "spillover effect*" OR "symmetric price transmission*" OR "asymmetric price transmission*") AND ("olive" OR "olives" OR "edible oil" OR "vegetal product" OR "vegetal products" OR "extra virgin olive oil" OR "lampante olive oil" OR "virgin olive oil" OR "crude olive-pomace oil" OR "olive-pomace oil" OR "refined olive oil" OR "refined olive-pomace oil" OR "seasame oil" OR "acai oil" OR "almond oil" OR "amaranth oil" OR "apple seed oil" OR "apricot oil" OR "argan oil" OR "avocado oil" OR "babassu oil" OR "beech nut oil" OR "ben oil" OR "black seed oil" OR "blackcurrant seed oil" OR "borage seed oil" OR "borneo tallow nut oil" OR "brazil nut oil" OR "butternut squash seed oil" OR "canola oil" OR "carob pod oil" OR "cashew oil" OR "cocklebur oil" OR "cocoa butter" OR "coconut oil" OR "cohune oil" OR "coriander seed oil" OR "corn oil" OR "cottonseed oil" OR "dammr oil" OR "date seed oil" OR "grape seed oil" OR "grapefruit seed oil" OR "hazelnut oil" OR "hemp oil" OR "kapok seed oil" OR "kenaf seed oil" OR "lallemantia oil" OR "lemon oil" OR "linseed oil" OR "macademia oil" OR "mafura oil" OR "marula oil" OR "meadowfoam seed oil" OR "mongongo nut oil" OR "mustard oil" OR "niger seed oil" OR "nutmeg butter" OR "okra seed oil" OR "orange oil" OR "palm oil" OR "papaya seed oil" OR "peanut oil" OR "pecan oil" OR "pequi oil" OR "perlla seed oil" OR "persimmon seed oil" OR "pili nut oil" OR "prime nut" OR "pistachio oil" OR "pomegranate seed oil" OR "poppyseed oil" OR "pracaxil oil" OR "prune kernel oil" OR "pumpkin seed oil" OR "quinoa oil" OR "ramtil oil" OR "rapeseed oil" OR "rice bran oil" OR "royle oil" OR "sacha inchi oil" OR "safflower oil" OR "sapote oil" OR "seje oil" OR "shea butter" OR "soyben oil" OR "stillingia oil" OR "sunflower oil" OR "tall oil" OR "taramira oil" OR "tea seed oil" OR "thristle oil" OR "tigernut oil" OR "tobacco seed oil" OR "tung oil" OR "vernonie oil" OR "walnut oil" OR "watermelon seed oil" OR "wheat germ oil")	Date: 1993-2020	No language selection	398	0	398		24/04/2020
12	**WILEY ONLINE**	("price transmission" OR "price transmitted" OR "price relation" OR "price relations" OR "price co-movement" OR "price co-movements" OR "price comovement" OR "price independence" OR "price independencies" OR "price inter-dependence" OR "price inter-dependencies" OR "price interdependence" OR "price interdependencies" OR "price dispersion" OR "price dispersions" OR "price volatility" OR "price regime" OR "price regimes" OR "price inter-relationship" OR "price inter-relationships" OR "price interrelationship" OR "price interrelationships" OR "price inter-relation" OR "price inter-relations" OR "price interrelation" OR "price interrelations" OR "price pass-through" OR "price pass through" OR "price integration" OR "price link" OR "price links" OR "price linkage" OR "price linkages" OR "price determinant" OR "price determinants" OR "price determination" OR "price spillover" OR "price symmetry" OR "price symmetries" OR "price asymmetry" OR "price asymmetries" OR "price shock" OR "price shocks" OR "price convergence" OR "market integration" OR "law of one price" OR "LOP" OR "LOOP" OR "price signal" OR "price signals" OR "price pattern" OR "price patterns" OR "spillover effect") AND ("olive" OR "olives" OR "edible oil" OR "vegetal product" OR "vegetal products" OR "extra virgin olive oil" OR "lampante olive oil" OR "virgin olive oil" OR "crude olive-pomace oil" OR "olive-pomace oil" OR "refined olive oil" OR "refined olive-pomace oil" OR "seasame oil" OR "acai oil" OR "almond oil" OR "amaranth oil" OR "apple seed oil" OR "apricot oil" OR "argan oil" OR "avocado oil" OR "babassu oil" OR "beech nut oil" OR "ben oil" OR "black seed oil" OR "blackcurrant seed oil" OR "borage seed oil" OR "borneo tallow nut oil" OR "brazil nut oil" OR "butternut squash seed oil" OR "canola oil" OR "carob pod oil" OR "cashew oil" OR "cocklebur oil" OR "cocoa butter" OR "coconut oil" OR "cohune oil" OR "coriander seed oil" OR "corn oil" OR "cottonseed oil" OR "dammr oil" OR "date seed oil" OR "grape seed oil" OR "grapefruit seed oil" OR "hazelnut oil" OR "hemp oil" OR "kapok seed oil" OR "kenaf seed oil" OR "lallemantia oil" OR "lemon oil" OR "linseed oil" OR "macademia oil" OR "mafura oil" OR "marula oil" OR "meadowfoam seed oil" OR "mongongo nut oil" OR "mustard oil" OR "niger seed oil" OR "nutmeg butter" OR "okra seed oil" OR "orange oil" OR "palm oil" OR "papaya seed oil" OR "peanut oil" OR "pecan oil" OR "pequi oil" OR "perlla seed oil" OR "persimmon seed oil" OR "pili nut oil" OR "prime nut" OR "pistachio oil" OR "pomegranate seed oil" OR "poppyseed oil" OR "pracaxil oil" OR "prune kernel oil" OR "pumpkin seed oil" OR "quinoa oil" OR "ramtil oil" OR "rapeseed oil" OR "rice bran oil" OR "royle oil" OR "sacha inchi oil" OR "safflower oil" OR "sapote oil" OR "seje oil" OR "shea butter" OR "soyben oil" OR "stillingia oil" OR "sunflower oil" OR "tall oil" OR "taramira oil" OR "tea seed oil" OR "thristle oil" OR "tigernut oil" OR "tobacco seed oil" OR "tung oil" OR "vernonie oil" OR "walnut oil" OR "watermelon seed oil" OR "wheat germ oil")	Date: 1993-2020	Search term (Title-Abstract-Keyword), Wildcards CANNOT be used at the start of a search term (*tension) or when searching for phrases in quotes ("tobacco smok*"). English language in the selection of papers after - not as criterion on Wiley For the subjects: had to select each one separate - couldn't choose more than one. So some articles may be repeated across the subjects	2450	1128	1322		05/04/2020
13	**Extra papers/ hand added - pdf**	olive oil and price transmission, olive oil and market integration, olive oil and law of one price, olive oil and symmetry/asymmetry, Olive oil and all the keywords for price	Date: 1993-2020	search google + references from papers + academia + researchgate +Taylor & Francis	102	0	107		09/2019-today
	TOTAL				9937	1918	8126		

APPENDIX B

SYSTEMATIC MAP – SUMMARY TABLE OF STUDIES INCLUDED FOR QUALITATIVE ANALYSIS – Horizontal Price Transmission

Author/s	Product	Countries	Type of HPT	Methodology	Data			Results
					Type	Period	Frequency	
Peri and Baldi (2010)	Rapeseed Oil, Sunflower Oil	EU	Agricultural vs Non-Agricultural	Johansen Cointegration, TVECM, Exogeneity Causality test	RP	2005-2007	Weekly	PMI APT
Hassouneh *et al.* (2012b)	Sunflower Oil, Crude Oil	ES	Agricultural vs Non-Agricultural	Cointegration, VECM	RP and WP	2006-2010	Weekly	MI APT
Ziegelbäck and Kastner (2011)	Rapeseed oil	FR	PVT Contracts/Future Markets	TVECM, Threshold Cointegration - Balke and Fomby (1997)	FC	2005-2010	Daily	MI regime-dependent APT
Vacha *et al.* (2013)	Gasoline, Diesel, Crude Oil, Corn, Wheat, Soybeans, Sugarcane and Rapeseed Oil	DE	Cross-commodity Agricultural vs Non-Agricultural	Wavelet Coherence analysis, Granger Causality	CP	2003-2011	Weekly	MI Granger Causality: Corn and diesel are leaders to ethanol and biodiesel. APT
Serra and Zilberman (2013)	Rapeseed Oil, Palm Oil, Soybean Oil, Sunflower Oil	US, BR, DE, EU, CN, TR, ES	PVT Agricultural vs Non-Agricultural	Scoping Literature Review	51 time series-research papers	2006-2012	N/A	MI

Key:

APT – Asymmetric Price Transmission	MI – Market Integration	RP – Retail Prices
CP – Consumer Prices	PMI – Partial Market Integration	WP – Wholesale Prices
FC – Future Contracts	PVT – Price Volatility Transmission	

APPENDIX C

SYSTEMATIC MAP – SUMMARY TABLE OF STUDIES INCLUDED FOR QUALITATIVE ANALYSIS – SPATIAL Price Transmission

Author/s	Product	Countries	Methodology	Data			Results
				Type	Period	Frequency	
Emmanouilides *et al.* (2014)	Extra Virgin Olive Oil and Lampante Olive Oil	ES, IT, GR	Granger Causality, Copulas	WP	2002-2012	Monthly	MI APT
Fousekis and Klonaris (2002)	Extra Virgin Olive Oil and Virgin Olive Oil	ES, IT, GR	Johansen Cointegration, VECM, Forecast Error Variance Decomposition	WP	1992-1998	Monthly	MI LOP is rejected
Hamulczuk *et al.* (2019)	Rapeseed Oil	UA, EU	Johansen Cointegration, VECM, TAR, Forecast Error Variance Decomposition, Impulse Response Analysis	CPT, export price	2008-2018	Weekly	MI APT

Key:

APT – Asymmetric Price Transmission	WP – Wholesale Prices
CPT – Carriage Paid To	
LOP – Law of One Price	

APPENDIX D

SYSTEMATIC MAP – SUMMARY TABLE OF STUDIES INCLUDED FOR QUALITATIVE ANALYSIS – Vertical Price Transmission

Author/s	Product	Countries	Methodology	Data			Results
				Type	Period	Frequency	
Tifaoui and von Cramon-Taubadel (2017)	Butter	DE	Johansen Cointegration, Cointegration Engle-Granger, VECM (Symmetric/Asymmetric)	RP and WP	2005-2010	Weekly	APT
Bussea *et al.* (2012)	Rapeseed Oil, Soy Oil	DE	Johansen Cointegration, Markov-switching VECM	FOB, CP, WP	2002-2009	Weekly	APT

Key:

APT – Asymmetric Price Transmission	RP – Retailer Prices
CP – Consumer Prices	WP – Wholesale Prices
FOB – Free on Board	

APPENDIX E

SYSTEMATIC MAP – SUMMARY TABLE OF STUDIES INCLUDED FOR QUALITATIVE ANALYSIS – Price Volatility Transmission

Author/s	Product	Countries	Methodology	Data			Results
				Type	Period	Frequency	
Bergmann *et al.* (2016)	Butter, Palm Oil, Crude Oil	EU and World	VAR, GARCH, Causality, Wald tests	WP, FOB, CIF	1995-2015	Monthly and Bi-Weekly	MI APVT
Abdelradi and Serra (2015a)	Pure Biodiesel, Brent Oil, Rapeseed Oil	EU	Johansen Cointegration, VECM, MGARCH BEKK, DCC MGARCH	WP, Spot prices	2008-2012	Weekly	APVT
Abdelradi and Serra (2015b)	Biodiesel, Sunflower Oil, Crude Oil, Soybean, Palm Oil	ES	Johansen Cointegration, VECM, BEKK	FOB, Spot prices	2006-2010	Weekly	APVT
Hasanov *et al.* (2016)	Crude Oil, Soybean Oil, Sunflower Oil, Rapeseed Oil	EU	GARCH-BEKK, Asymmetric VAR, Granger Causality, Generalised IRF	FOB, WP, Spot prices	2008-2015	Daily	APVT
Panagiotou (2015)	Extra Virgin Olive Oil	IT, ES, GR	Johansen Cointegration, VEC, GARCH-BEKK	WP	2000-2014	Monthly	APVT

Key:

APT – Asymmetric Price Transmission	FOB – Free on Board
APVT – Asymmetric Price Volatility Transmission	
CIF – Cost, Insurance and Freight	