



Asymmetric price volatility transmission in the fresh sardine value chain: The case of Spain

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ABSTRACT

This paper investigates the transmission of price volatility along the Spanish fresh sardine (*Sardina pilchardus*) value chain. Examining prices from the first-hand sale, wholesale, and retail markets using an asymmetric multivariate GARCH model reveals the retail market exhibits the lowest volatility. Therefore, only a small portion of the volatility from the first-hand sale and wholesale markets is transferred to consumers. Additionally, asymmetries are identified in the transmission of price volatility along the fresh sardine value chain. These suggest that information is not instantaneously transmitted along the supply chain, indicating imperfect market efficiency. Additionally, the wholesale market seems to exert market power, leading to less transparent price formation and potential anti-competitive practices. To reduce price volatility, several policy recommendations can be considered. These include promoting profitable sardine aquaculture to stabilise supply despite technological challenges and implementing sustainable fisheries management practices with improved regulation and more transparent individual transferable quota systems, particularly in the Gulf of Cádiz. Greater market transparency through improved traceability and a simplified supply chain may lead to a more competitive market, reducing volatility in first-hand sales. This volatility fuels the competitive race to exhaust quotas rapidly, resulting in lower prices and reduced fishers' income. Lastly, it is crucial to consider how external factors, such as online sales platforms, climate change, and recruitment variability in small pelagic species, affect fish landings. Identifying the causes and transmission mechanisms of price volatility can support targeted management and transparency interventions to stabilise revenues and ensure fair competition, benefiting both consumers and fishers.

1. Introduction

The analysis of price volatility is crucial in the fishing and aquaculture sector. These kinds of activities include risk, as noted by Dahl and Oglend [24], and as a result, there may be some price volatility. As price volatility is a measure of price uncertainty, it influences income, fishing expenses, fish stock pressure, food security and welfare [25,75]. Furthermore, price volatility has a big impact on the aquaculture sector and seafood markets, according to Asche et al. [5]. These price fluctuations can be produced by shifts in supply and demand. Production shocks and seasonality could be the cause of the former. Since almost 40 % of the world's fish production is traded globally, the latter may be the result of shifting exchange rates and trade restrictions in addition to changes in the availability of close substitutes.

Similarly, the OECD/FAO [71] has identified a number of risks and uncertainties that could significantly affect the fishing sector between

2022 and 2031. These include volatility in energy markets, management strategies, environmental regulations, stock status, and domestic fishery laws. For companies that produce seafood and those in the supply chain, price variations are also important since they affect cash flow and revenue due to production and market risks. Thus, the seafood sector has uncertainty as a result of this price volatility, which eventually leads to varying profitability over time. All participants involved in the supply chain are impacted by price volatility. Assefa et al. [10] emphasise how crucial it is for risk managers and legislators to comprehend the magnitude and direction of price volatility transmission in food supply chains. On one side, supply chain price volatility is influenced by policy changes that impact price volatility in primary input markets. However, if volatility is not transmitted along the markets of the value chain, it is impractical to expect that stabilising one market will lead to stability in other supply chain markets. Decision makers must thus take diverse actions in the various markets throughout the value chain to respond to

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these circumstances. Assefa et al. [10] also note that the transmission of volatility along the supply chain enhances the accuracy of agents' pricing forecasts in other markets. This affects value chain players' decisions on hedging. There may be cross-hedge linkages created by volatility spillover between the markets of the value chain. These factors make price volatility analysis important for ascertaining how susceptible each supply chain actor is to price volatility as well as how price volatility is transmitted along the value chain. As pointed out by Ferrer-Pérez and Gracia-de-Rentería [38], when creating their plans for risk management and risk avoidance, policymakers and value chain actors could find it helpful to examine price volatility. The analysis of price volatility of the European sardine is necessary for a number of reasons. First, since fishing is unpredictable, the supply of European sardine is unstable while demand is relatively steady. Second, volatile fuel prices have an impact on European sardine fishing.

Thus, the policy relevance of studying price volatility transmission in the fishing sector is significant for several reasons. First, regarding risk management, understanding how price volatility is transmitted along the value chain helps fishing sector stakeholders and policymakers develop risk management plans. This is essential for the fishing sector to remain sustainable and to stabilise incomes [38,40]. Second, in terms of market stability, specific interventions can be created to stabilise prices by determining which markets in the value chain exhibit the highest levels of volatility. This can help to lessen the effect of price shocks on the various supply chain levels [10]. Third, in terms of trade and regulation, knowing how price volatility is transmitted can help establish trade rules and regulations that mitigate the negative effects of global market fluctuations. This is important due to the significance of international seafood trade [17]. Fourth, it can help to guide economic policies and planning, especially in areas that heavily depend on fishing. This may result in more effective industry support and resource allocation [60]. Fifth, regarding sustainability, the study of price volatility transmission can show how environmental variables and management strategies affect price volatility. Consequently, its analysis might draw attention to the necessity of better regulatory frameworks that support the long-term sustainability of fish stocks [38,40]. Sixth, concerning consumer protection, customers can be protected against sudden price increases that may have an impact on food security and affordability by ensuring that price volatility is minimised at the retail level [60]. Finally, understanding how volatility is transmitted will help companies in the seafood supply chain make better financial plans and investment decisions, resulting in more resilient businesses [75].

As pointed out by Ferrer-Pérez and Gracia-de-Rentería [38], price volatility analysis and price-level transmission are complementary concepts. Assefa et al. [10] state that price volatility transmission investigates the relationship between the conditional variance of prices, whereas price-level transmission examines the relationship between the conditional mean of prices. As for the investigation of vertical price transmission, some research papers about the seafood market should be mentioned. For example, Fernández-Polanco and Llorente [34] examined the value chains of hake, anchovy, and mackerel in Spain. Guillotreau [44], Asche et al. [6,8], Landazuri-Tveteraas et al. [63], Svanidze et al. [85] and Straume et al. [83] investigated the salmon market. Asche et al. [7] studied the cod market in Norway. Jiménez-Toribio and García-del-Hoyo [55] analysed the Spanish red sea bream supply chain. Jiménez-Toribio et al. [56] investigated the world market and the major European markets of canned and frozen tuna. Fernández-Polanco and Llorente [33] and Fernández-Polanco et al. [35] studied gilthead seabream in the Spanish market. Using eight fish species (tuna, farmed salmon, plaice, cod, hake, Alaska pollock, redfish, and saithe) from the German market, Bittmann et al. [14] examined the significance of nutritional product differentiation in vertical price transmission. Finally, Deb et al. [26] analysed price transmission and market integration in the value chain of the four most consumed aquaculture fish species in Bangladesh (pangasius, silver carp, rohu, and tilapia).

Furthermore, research has been conducted on asymmetric price

transmission in European seafood markets throughout the value chain. In this sense, pricing changes at one level in the value chain are passed on to subsequent levels at varying rates. This is significant, according to Ferrer-Pérez and Gracia-de-Rentería [38], since it allows us to ascertain whether rising upstream prices have the same impact on middle and lower prices as falling prices. It also enables us to investigate whether price volatility at the middle and upstream stages of the value chain is lessened by an increase (or drop) in downstream prices. It is worth noting that a number of papers - including those by Ankamah-Yeboah and Bronnmann [4], Gizaw et al. [42], Guillen and Franquesa [43], Jaffry [54], and Simioni et al. [79] - confirm asymmetric price transmission. However, Acharjee et al. [2] concluded that while long-term price transmission for Pangas, Rui, Catla and Tilapia in Bangladesh exhibits a combination of symmetry and asymmetry, especially in rural markets, short-term price transmission is largely symmetric.

Nevertheless, Dahl and Oglend [24] noted that there have not been many papers on the examination of volatility in fish prices. After examining price volatility in wild and aquaculture products, Dahl and Oglend [24], Asche et al. [5], and Dahl [21] came to the conclusion that aquaculture product prices have less volatility than those of wild product prices. Furthermore, a number of interesting studies have examined the rising price volatility of salmon. These include papers by Oglend [72], Solibakke [82], Bloznelis [15], Asche et al. [9], and Dahl and Yahya [25], that examine price volatility dependence dynamics in the short, medium, and long run with markets of other species. Dahl and Jonsson [22,23] have examined the issue of interrelated dynamics and volatility spillover in the seafood and aquaculture markets. Dahl and Jonsson [22] investigate the price volatility spillover between seafood originating from fisheries and aquaculture, concluding that there is less volatility in aquaculture output due to the transmission of volatility from wild to aquaculture production, as previously reported by other studies. Dahl and Jonsson [23] conducted an analysis of the price volatility spillover between the EU, Japan, and the USA, the three major regional import markets for fish and crustaceans. Their findings indicate a significant time-varying volatility spillover from net exporting economies to net importing markets. Deb et al. [27] study fish price volatility dynamics in Bangladesh, concluding that increased aquaculture production, which stabilises fish prices by ensuring a steady supply, has reduced the volatility of fish prices in recent years. The results highlight how aquaculture may improve food security and lessen market volatility. Deb and Li [28] analyse the price volatility spillover between capture fisheries and aquaculture markets. They conclude that aquaculture products exhibit significant long-term volatility spillovers to capture fisheries, suggesting that developments in aquaculture markets have the potential to stabilise or destabilise larger fish markets. They recommend that policy interventions focus on the pangasius and tilapia markets because they are essential for stabilising the fish markets as a whole.

Lastly, there are four papers on volatility price transmission along the value chain that should be mentioned. First, using an exponential generalised autoregressive conditional heteroskedasticity (EGARCH) model to analyse price volatility transmission along the US catfish value chain, Buguk et al. [18] conclude that significant volatility is transmitted from menhaden, corn, and soybean to catfish prices (i.e. feed, farm, and wholesale prices). Second, Ferrer-Pérez and Gracia-de-Rentería [38] use an asymmetric MGARCH model and a vector autoregressive (VAR) model to study price volatility transmission along the fresh wild hake value chain in Spain using first-hand sale, wholesale, and retail prices. They conclude that the value chain has asymmetric effects and time-varying volatility. Third, García-del-Hoyo et al. [40] examine the price volatility transmission of fresh anchovies among different markets along the value chain in Spain using the same methodology as Ferrer-Pérez and Gracia-de-Rentería [38]. They also conclude the existence of time-varying volatility and asymmetric effects in the value chain of fresh anchovies. Fourth, Surathkal et al. [84] study the dynamics of price volatility spillover in the US catfish market using a

multivariate generalised autoregressive conditional heteroskedasticity (GARCH) model. The results allow them to conclude that the volatility spillover between catfish and local feed ingredients is bi-directional when local feed ingredients are used.

The plan of this paper is as follows. In Section 2, the Spanish sardine market is described. In Section 3, the data used are presented, and we outline the methodology and theoretical basis for the study. In Section 4, we present and discuss our empirical analysis. In Section 5, some concluding remarks are provided.

2. Spanish market for European sardines

2.1. Supply and demand in Spain

The European sardine (*Sardina pilchardus*) is a small pelagic fish that inhabits in the Northeast Atlantic, from Iceland and Norway, in the Mediterranean Sea and in the vicinity of the African coast of the East Central Atlantic from the Strait of Gibraltar to the waters of Senegal. Stocks appear to be shifting to higher latitude areas due to climate change [19,39,68]. However, this displacement does not prevent the upwelling area between the Strait of Gibraltar and Senegal from being the location which currently provides 86 % of the catches according to FAO data. In this area the Moroccan and Mauritanian fleets currently operate almost exclusively (96 % of 1.33 million mt obtained in 2022). Catches in the Northeast Atlantic peaked at 0.27 million mt in 1961 (representing 52 % of the world's European sardine landings in that year) but currently stand at just 0.08 million mt (a share of 5.3 %). This is an area where only EU vessels catch sardine. Finally, catches in the Mediterranean and Black Seas account for 8.8 % of global catches, amounting to 0.136 million mt in 2022. Nonetheless, it only represents 47.7 % of the historical maximum in this area, which was reached in 1987, and has declined sharply since then. In this area, the current EU-27 fleet accounts for 51 % of landings. Although it is far from its historical peak in 1981 with 0.14 million mt, it is twice the current level.

For the EU-27 as a whole, the importance of European sardines over the total fishery landings is close to 5.5 %, with 166,146 mt in 2022. It is the lowest in the historical series and it only represents 30 % of the historical maximum catches of the EU-27 countries for the period 1950–2022. The main producing countries are currently Croatia (23.6 %), Spain (16.7 %), France (15.8 %), Portugal (15.2 %), the Netherlands (10.3 %) and Italy (7.9 %), which accounts for 89.6 % of the total catches. In the 1950s, the current EU-27 countries accounted for 75 % of world landings of European sardine. If we exclude the Eastern Central Atlantic, the relative weight of the EU-27 increases. It is 51 % in the Mediterranean and Black Seas and the total landings in the Northeast Atlantic.

Spain currently represents 1.7 % of global catches, with 22.1 % of those catches in the Northeast Atlantic and 6.8 % in the Mediterranean and Black Seas, reaching 27,664 mt in 2022. In relation to the EU-27, Spanish catches represent 13 % of the catches obtained in the Mediterranean and Black Seas. Historically, Spain represented 28 % of global catches and 59 % of the EU in 1984. Despite the decline, sardines represent 3.7 % of total Spanish fish landings. Sardines are fished by vessels equipped with purse seines. However, in the past sardines were also fished with pelagic trawlers, beach seines and, to a lesser extent, drift nets. In the Northeast Atlantic, Spanish catches currently stand at less than 29.8 % of the 1980/89 catches, while in the Mediterranean they barely exceed 11.4 % (Fig. 1). This is partly due to a reduction in stocks and also to the reduction in fleets. Current estimates by ICES [50] for the stock of sardine recruits in the Northeast Atlantic areas where the Spanish fleet operates barely reach 33 % of the assessments for 1980/89, with the purse seine fleet having been reduced from 1224 vessels in 1984 to just 319 vessels in 2022. In the Mediterranean, GFCM [41] considers the stocks in the subareas where the Spanish fleet operates as extremely overexploited and with very low recruitment, with the reduction of the fleet also being high, going from 365 vessels in 1984 to

just 191 in 2022.

In addition to the catches made by the Spanish fleet, significant quantities of fresh or chilled sardine enter the Spanish market from other EU countries. They total between eleven and nineteen thousand mt per year, with 50–60 % coming from Portugal, 10–30 % from Italy, 9–14 % from France and 10–17 % from Croatia. Huge quantities of frozen sardines are also imported. They are between 13 and 53 million kg per year in the last decade. However, they are destined for industrial processing. The overall supply of fresh or chilled sardines in Spain was around 83,000 mt between 2000 and 2005. It decreased to around 40,000 mt per year between 2017 and 2023 due to the reduction in catches. It is a reduction of 54.5 % in supply and 63 % in landings of catches by the fishing fleet.

The reduction in catches has also led to a reduction in sardine consumption. As shown in Fig. 2, in the early 1980s, per capita consumption was 2.36 kg per inhabitant per year, falling to 0.41 kg in the 2020/21. In contrast, the average retail price in real terms (in 2021 euros) rose from 3.21 €/kg in 1980/81 to 5.62 €/kg in 2020/21. Per capita consumption of fresh or chilled sardines decreased by 82.7 % and total household consumption diminished by 78.2 %, while the unit price increased in real terms by 75.2 %. On the other hand, per capita consumption of fresh or chilled fishing products only decreased by 3.9 %, and total consumption diminished by 23.6 %, from 665,869 mt in 1980/81 to 630,239 mt in 2020/21.

Comparing the average real prices of all fresh or chilled fishing products at retail level with those of sardines (Fig. 2), this species has always been characterised by an average price well below the average price for fishing products, standing at 38 % of the average price in 1980/81. However, as landings have been reduced, this relative price has increased significantly, standing at 59.8 % of the average price in 2000/01 and at 71.3 % in 2020/21.

If we consider the apparent consumption - fish landings of fresh or chilled sardines, plus imports minus exports - total household consumption of fresh or chilled sardines represented 66 % of the apparent consumption in 2000/01 and 64 % in 2020/21, while the remainder was devoted to other uses (processing into canned, salted and frozen products, as well as consumption by non-residents) (Fig. 3). A share of this household consumption is purchased in retail establishments for consumption at home and another share is consumed in hotels and catering establishments. The latter share has progressively declined from 12 % of apparent consumption in 2000/01 to only 5 % in 2020/21.¹

Sardine catches are sold in first-hand sale markets, which are mostly managed by fishers' guilds and shipowners' associations. Fig. 4 shows the high sensitivity of average real first-hand sale prices to changes in fresh sardine landings.

2.2. Supply and demand of sardines in Andalusia

The Autonomous Community of Andalusia is located in the south of the Iberian Peninsula, on both sides of the Strait of Gibraltar. It is an area with a long tradition of fishing in general, and in particular of European sardine fishing. Traditionally, the fleet based in Andalusian ports has operated in the fishing grounds of the Gulf of Cádiz, included in the southern part of FAO area 27 "Northeast Atlantic" (ICES subdivision IXa South), and in the waters of GFCM subdivision GSA01 ("North Alboran Sea") of FAO area 37 "Mediterranean and Black Seas". In addition, due to their proximity, from the 1920s, purse seiners based in ports close to the Strait of Gibraltar (Barbate, Algeciras, Tarifa) operated in the waters of northern Morocco (FAO area 34 "Eastern Central Atlantic"). These were joined by vessels from ports along the coast of the province of Huelva (Ayamonte, Isla Cristina) in the 1930s. Fig. 5 shows the evolution of European sardine landings in Andalusian ports according to their origin

¹ This small share of non-household consumption was not caused by COVID restrictions, as it accounted for 5.2 % in 2019 and 5.1 % in 2022.

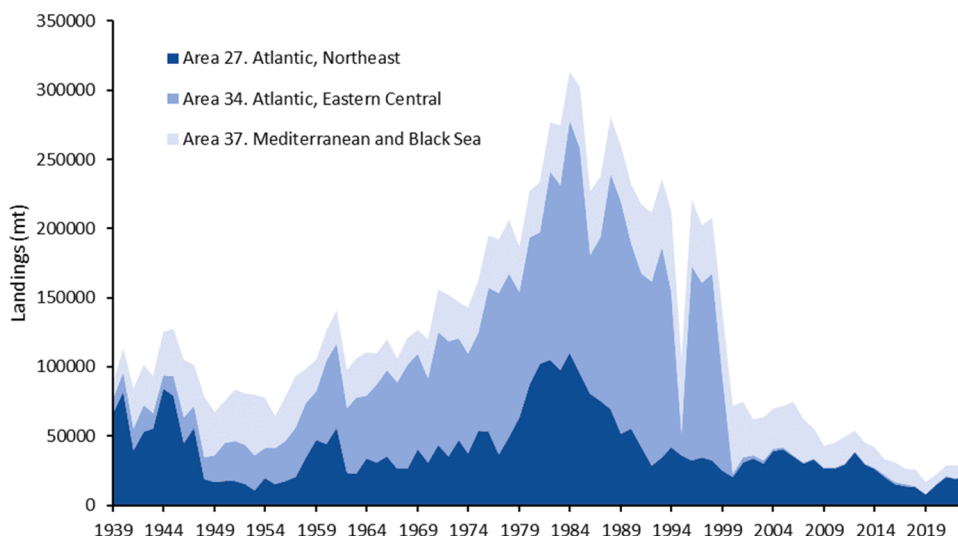


Fig. 1. European sardine landings in Spain in the main FAO fishing areas (1939–2023).

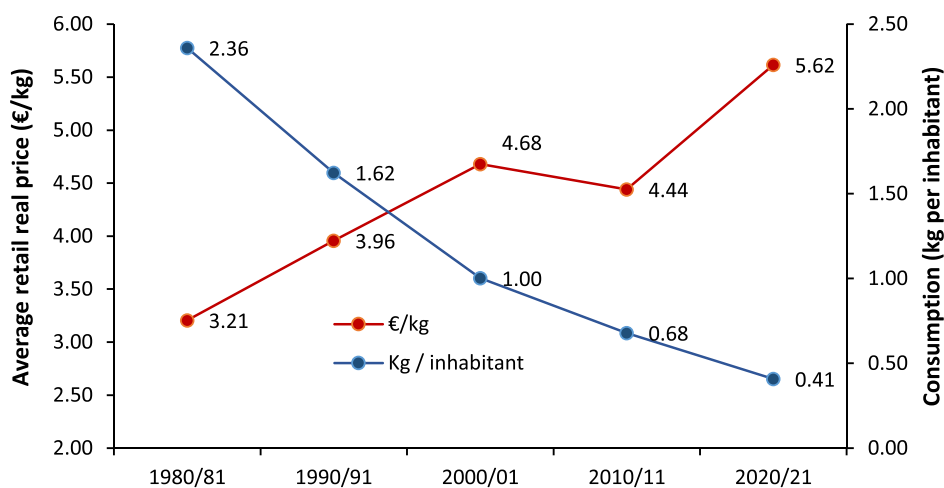


Fig. 2. Evolution of per capita consumption and real retail price (base year = 2021) of fresh or chilled sardines in Spain (1980–2021). Food Consumption Panel [66]; INE [52,53].

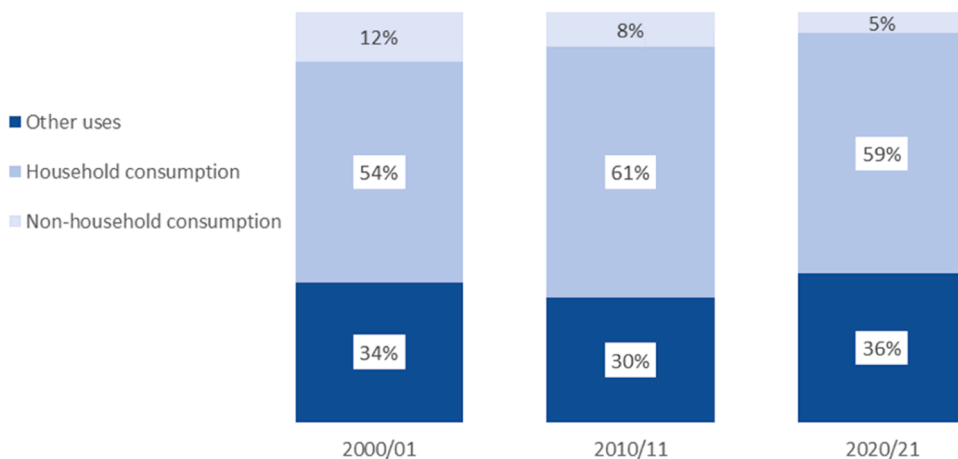


Fig. 3. Distribution (%) of apparent supply according to use.

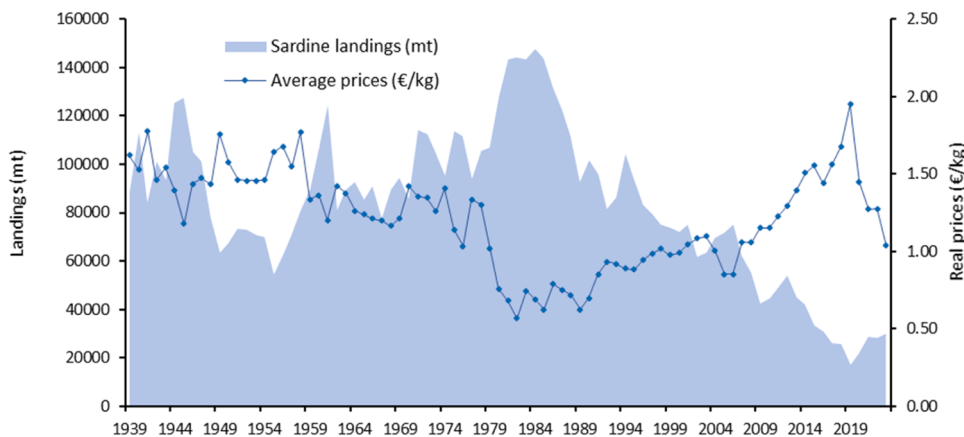


Fig. 4. Fresh and chilled sardine landings (mt) and average real prices in first-hand sale market (€/kg) (base year = 2021) in Spain (1939–2023).

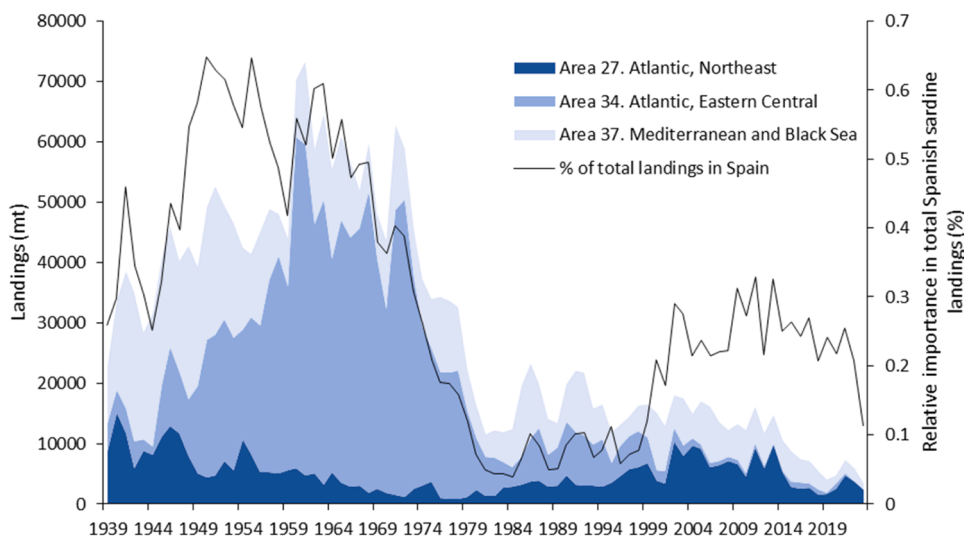


Fig. 5. Sardine landings in Andalusian ports according to capture area and relative importance in total Spanish sardine landings (1939–2023).

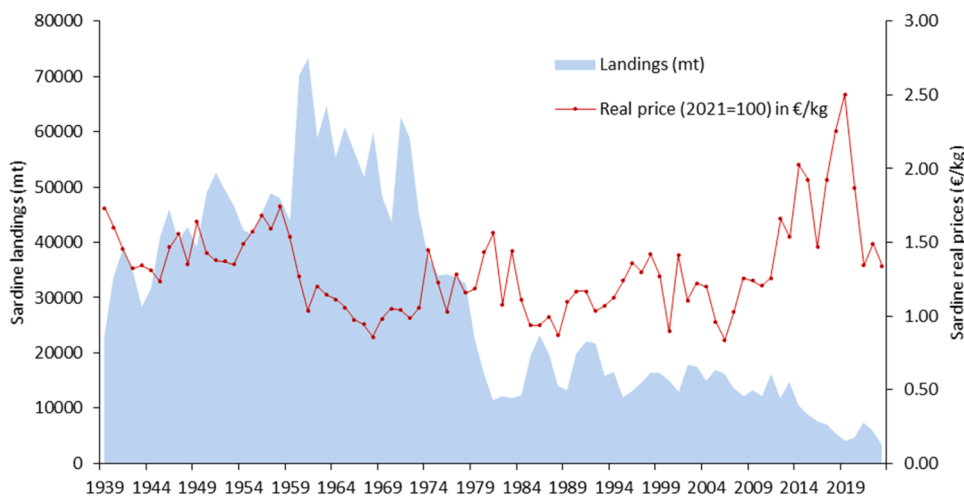


Fig. 6. Sardine landings (*Sardina pilchardus*) of the Andalusian fishing fleet and real prices (2021 =100) in first-hand sale markets (1939–2023).

and the percentage that these landings represent over the Spanish total.

During the period 2000–2022, the importance of European sardine landings in Andalusian ports as a proportion of the Spanish total has remained at around 24 % of the total, but in 2023 it fell to 11 %. Fig. 6

shows the evolution of sardine landings of the Andalusian fishing fleet and real prices in first-hand sale markets. However, the number of vessels dedicated to purse seine fishing has also experienced a severe reduction. Thus, in 1982 there were a total of 412 purse seiners

operating, but in 2002 there were only 249 (39.6 %) and over the following two decades, by 2022, the number of vessels reduced to 147.

In addition to fishing landings, there are huge flows of fresh and chilled sardine imports and, to a lesser extent, exports, carried out by Andalusian companies. Over the last two decades, imports have actually increased tenfold. They rose from 206 mt in 2001 to 2053 mt in 2023. Therefore, it is an increase of 897 %. On the other hand, exports have experienced a smaller increase since 2001. They rose from 107 mt in 2001 to 526 mt in 2023. Therefore, it is an increase of 391 %. Thus, fish landings currently account for 70 % of the apparent supply of fresh and chilled sardines, compared to almost 100 % until 2018.

Annual per capita consumption in Andalusian households in 2020/21 amounted to 0.41 kg/inhabitant, which has decreased by 73.2 % since 1990/91. In the same period, fish landings decreased by 66.9 %, while final consumer prices increased by 46.4 %. In contrast, prices obtained by fishers at first-hand sale have barely increased by 19.2 %. It is worth highlighting the increase in intermediation margins and the loss of fishers' share. In 1980/81 the first-hand sale price actually represented 50 % of the consumer price. Then, it remained between 40 % and 50 % until 2018, with margins falling sharply from that year onwards, to levels close to 30 %.

2.3. Market organisation in Andalusia

There are three basic stages in the market distribution channel of fresh or chilled sardines: the first-hand sale markets, the central wholesale markets as centres for the internal redistribution of fishing products and the retail market, made up of very different commercial typologies (Fig. 7). The interaction between these three levels sets up different types of market distribution channels, mainly traditional (fisher – first-hand sale - wholesaler - retailer - consumer) and modern (fisher – first-hand sale - retailer - consumer).

2.3.1. First-hand sale markets

In first-hand sale markets, the daily catches of the fishing fleets are sold at Dutch auctions. Given the mobility of sardine shoals and the perishable nature of sardines, vessels usually go to ports close to the place of capture, and their catches are sold there. Authorised buyers are usually wholesalers in origin, trading companies, and, increasingly, agents of large retail distribution chains (supermarkets). The wholesalers in origin sell to local retailers or wholesalers at the destination market, located in the Central Market Network (MERCASA), or in different facilities. The central markets also receive consignments sent by foreign wholesalers (imports) or those purchased by Spanish wholesalers to be sold, regardless of whether they are Spanish catches or imports.

Currently, only 63 % of the active first-hand sales markets (27) in Andalusia sell fresh or chilled European sardines. However, it is worth

Table 1
Summary of first-hand sale markets in 2002 and 2022.

	Fishing area				Total	
	Gulf of Cádiz		Alboran Sea		2002	2022
	2002	2022	2002	2022	2002	2022
A. Number of vessels	101	76	148	71	249	147
B. Sardines landings (mt)	12449	3777	5468	2135	17918	5912
C. Average landings per vessel (A/B)	123.3	49.7	36.9	30.1	72.0	40.2
D. Total number of first-hand sale markets	12	13	13	14	25	27
E. Number of first-hand sale markets with sardines	10	5	5	12	15	17
F. Number of vessels per first-hand sale market (A/E)	10.1	15.2	29.6	5.9	16.6	8.6
G. Average weight per first-hand sale market (mt) (B/E)	1244.9	755.4	1093.6	177.9	1194.5	347.7
H. Average price in first sale (€/Kg)	0.76	0.85	1.61	1.64	0.79	1.62
I. % of weight in 20 % largest first-hand sale markets	60.8 %	73.0 %	58.3 %	79.4 %	67.3 %	78.78 %

Sources: Fishing statistics from the Department of Agriculture, Fisheries, Water and Rural Development (CAPADR) of the Government of Andalusia. General Registry of the Operational Fishing Fleet (MAPA).

noting that the 20 % with the highest sales accounted for 78.8 % of total sales in 2022, which means an increase in the concentration of supply because this proportion was 67.3 % in 2002 (Table 1). Between 2002 and 2022, the average number of vessels per fishing market that actually auctioned sardines has halved, but there were notable differences between the ports of the Gulf of Cádiz and those of the Alboran Sea. In the former it has increased from 10.1 to 15.2 vessels/first-hand sale market and in the latter it has decreased from 29.6 to 5.9 vessels/first-hand sale market. Finally, the average sales per first-hand sale market has decreased drastically in the Alboran Sea (-83.3 %), while the reduction has been less severe in the ports of the Gulf of Cádiz (-39.3 %).

2.3.2. Wholesale markets

The Central Market Network (23 markets) conducts the wholesale

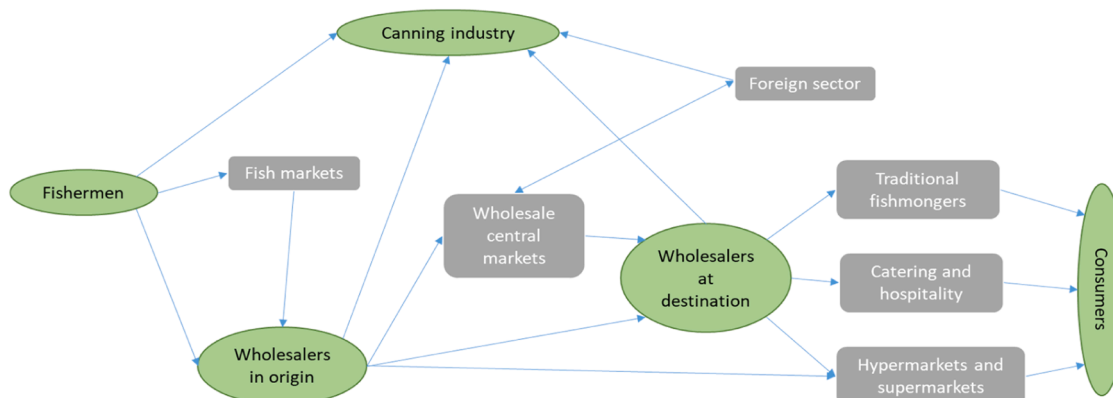


Fig. 7. Main trade channels of fresh sardines in Spain.

distribution of fishery products in Spain. Fresh or chilled European sardines are sold in 16 out of the 23 markets. A large part of the fish landings auctioned at the first-hand sale markets as well as imports (Portugal, France and Italy) are brought to these establishments. Although the quantities sold in these establishments follow a downward trend (a total of 25,740 mt in 2004 compared to 18,719 mt in 2023), they have significantly increased their share of the total apparent supply. Therefore, compared to 35 % in 2004, in 2011 they represented 44.3 % and in 2023 they accounted for 60.9 % of the apparent supply. There are six central markets in Andalusia, where 38.2 % of the total MERCASA sardine sales are sold. As a result, they have doubled their relative importance from the 23 % share they had in 2004.

However, all quantities auctioned in the Andalusian first-hand sale markets do not go to Andalusian MERCAS, nor do all quantities sold in the latter correspond to fish landings made in Andalusian ports or quantities imported by Andalusian companies. However, there are important two-way flows between different Spanish regions, according to quality, prices and times of the year. For example, in Mercamálaga, which is the most important market by sales, fish products come from the province of Málaga, but they also come from the neighbouring province of Cádiz and the much more distant province of Pontevedra. This unequal distribution of the quantities of fresh sardines sold is a consequence of the eating habits of the inhabitants in this area and the tourist activities and gastronomic traditions they offer to visitors (Table 2).

As can be seen in Fig. 8, the trend in the quantities sold in the Andalusian central markets is markedly upward. It has increased by 30 % in the period considered. However, this aggregate result hides a relevant fact, which is that only the central market of Málaga has had a positive performance (an increase of 178 %), while the remaining markets have lost market share to a greater or lesser extent. Furthermore, household and non-household consumption by residents (retail markets) is lower than the quantities sold in the MERCAS, which leads us to think that it is consumption by non-residents (tourists) which is determining the gap between the two series. Moreover, as can also be seen in Fig. 8, the apparent supply of sardines far exceeded household consumption and the quantities supplied in local markets in Andalusia. However, since then there has also been a deficit in the supply in Andalusian central markets with respect to consumption, and also with respect to the apparent supply. Therefore, huge flows of sardines sold in central markets in nearby regions finally converge on the Andalusian market, due to the changes experienced in the retail distribution sector.

2.3.3. Retail market

Over the last two decades, the retail market has experienced the greatest changes in the value chain. Consumption of fresh sardines in hotels and catering establishments has decreased by 81.9 % in the last two decades. This decrease is greater than that experienced by all fishery products (-57.9 %) and fresh fish (-51.2 %). Therefore, non-household consumption of sardines has decreased from 0.21 kg per inhabitant per year in 2002 to 0.04 kg per inhabitant per year in 2023. Furthermore, total consumption in Spain as a whole has gone from 1.23 kg per inhabitant per year in 2002 to 0.40 kg per inhabitant per year in 2023, while in Andalusia this reduction has been sharper, given that it started from higher levels of per capita consumption (1.30 kg per inhabitant). Therefore, it diminished 67.5 % between 2002 and 2023.

The retail distribution of fishing products in Spain has experienced significant changes over the last two decades [3]; [36]. Most sardine purchases have historically been concentrated in traditional establishments (fishmongers, stalls in food markets, etc.). However, the importance of this type of retail distribution fell from 46 % (2007) to 32.9 % (2023). This is due to an important change in purchases characterised by the concentration of most purchases of sardines in supermarkets, which increased from 42.4 % (2002) to 52.3 % (2023). The prices in traditional retail establishments are much higher than those in other types, at 103–114 % of the average price of each year, while the prices in supermarkets are between 91 % and 99 % of the average retail price. In addition, the effect of supply reductions on prices in traditional establishments is much greater than in supermarkets and hypermarkets.

Regarding changes in the distribution sector structure, there have been extreme changes in consumer habits [13,20,87]. Considering fresh sardines and anchovies together, household penetration reached 14.14 % in 2007, while it stood at 38.9 % in 2023. In Andalusia the percentages were 11.95 % and 40.43 % respectively. In 2007, the penetration in households in municipalities with fewer than 2000 inhabitants was 1.7 times higher than that of municipalities with more than 500,000 inhabitants. On the other hand, nowadays this difference has been reduced to 1.3. These changes are mainly due to the expansion of large retail distribution chains (Mercadona, Carrefour, Lidl, etc.), which are improving distribution in large cities, to the detriment of traditional establishments (fishmongers, stalls in food markets, etc.).

All these changes affect the evolution of prices at different levels of the value chain, as we analyse in the next section using biweekly data from the Observatory of Prices of the Food Chain of the Spanish Ministry of Agriculture, Fisheries, and Food and IDAPES of the Andalusian regional government.

Table 2
Importance of fresh or chilled sardine sales in the Central Market Network (MERCASA) in 2022.

	No. of whole- salers	Sardine sales			Total fish sales			Average sales per wholesaler		Importance of sardines (%) on total sales	
		mt	10 ³ €	€/kg	mt	10 ³ €	€/kg	mt	10 ³ €	of the Merca	of sardines
In Andalusia:											
Mercamálaga	25	4392	9812	2.23	35069	215000	6.13	1403	8600	12.5 %	23.4 %
Mercasevilla	40	1969	5607	2.85	40437	238545	5.90	1011	5964	4.9 %	10.5 %
Mercagranada	16	981	2728	2.78	14672	76000	5.18	917	4750	6.7 %	5.2 %
Mercacórdoba	10	354	964	2.72	5654	28000	4.95	565	2800	6.3 %	1.9 %
Mercagranada	16	981	2728	2.78	14672	76000	5.18	917	4750	6.7 %	5.2 %
Mercaalgeciras	2	55	152	2.76	1447	10000	6.91	724	5000	3.8 %	0.3 %
Total for Andalusia	109	8732	21991	2.52	111951	643545	5.75	1027	202	7.8 %	46.6 %
Other regions:											
Mercamadrid	137	1965	6429	3.27	169445	1362000	8.04	1237	9942	1.2 %	10.5 %
Mercavalencia	22	4420	12754	2.89	67265	521000	7.75	3058	23682	6.6 %	23.6 %
Mercabarna	60	1715	5505	3.21	185252	1728000	9.33	3088	28800	0.9 %	9.2 %
Mercazaragoza	11	1876	4719	2.52	28539	197000	6.90	2594	17909	6.6 %	10.0 %
Mercabilbao	23	476	1645	3.46	21297	171000	8.03	926	7435	2.2 %	2.5 %
Others	76	540	1687	3.12	74395	586555	7.88	979	7718	0.7 %	2.9 %
Total for the rest of Spain	329	10992	32740	2.98	546193	4565555	8.36	1660	13877	2.0 %	58.6 %
Total for Spain	422	18743	52003	2.77	621699	5019100	8.07	1473	11894	3.0 %	100.0 %

Sources: MERCASA [67] and annual reports of each wholesale market.

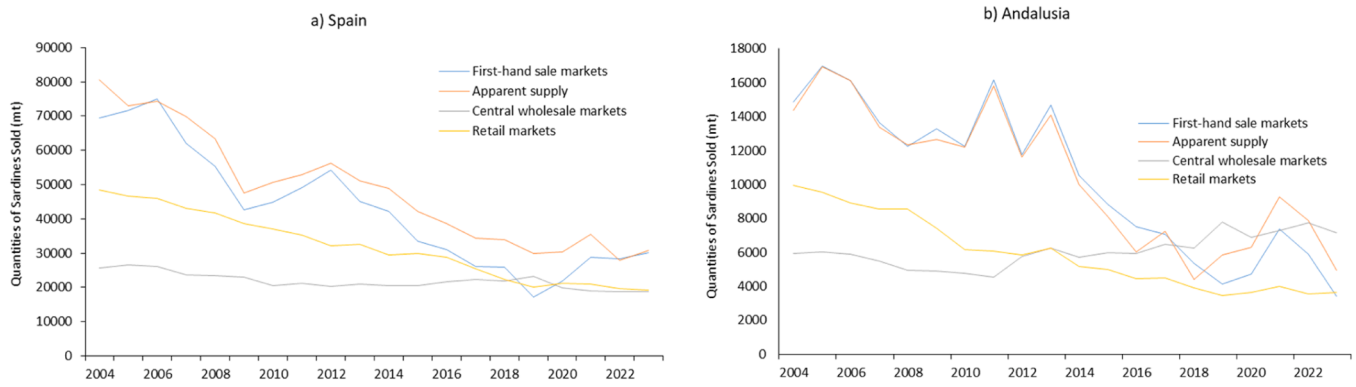


Fig. 8. Evolution of sales of fresh and chilled sardines (2004–2023) in Spain as a whole and in Andalusia according to the type of market.

3. Data and methods

The prices of fresh sardines in the first-hand sale (PSO), wholesale (PSM), and retail (PSD) markets of the value chain are used in this paper. The Observatory of Food Prices of the Spanish Ministry of Agriculture, Fisheries, and Food provides the prices for both the first-hand sale and wholesale markets. IDAPES serves as the source for retail market prices.² In this regard, it should be mentioned that 32.9 % of the total fresh sardine consumption in Spain between 2012 and 2023 is consumed by resident households in Andalusia, although it has decreased sharply to 19 % in 2022 and 2023. Furthermore, non-household consumption by residents and non-residents (national and foreign tourists) should be added. This means that nearly 50 % of the total fresh sardines traded in Spain are sold in the central wholesale markets located in Andalusia.

In all three markets of the value chain, the price behaviour is comparable. Fig. 9 shows prices at weekly frequency. However, we changed the data from weekly to biweekly frequency to decrease the amount of missing observations. For the remaining missing observations, we utilised linear interpolation. By calculating the average of weekly observations for a biweekly observation, average observations were used to change the frequency of the data. The 1st week of 2012 to the 52nd week of 2023 is the time period that is taken into consideration. Consequently, this paper took into account 313 biweekly observations. Furthermore, prices were converted to logarithms to obtain well-behaved error terms. According to Bierlen et al. [12], reduction in heteroskedasticity and normality in error terms are produced by the data logarithmic transformation. As Sidhoum and Serra [78] point out, it makes the model estimation and result interpretation easier.

The descriptive statistics for each of the three prices taken into consideration are shown in Table 3. The coefficient of variation indicates that the first-hand sale price has the highest variability, followed by the wholesale price and closely followed by the retail price. As the skewness

² As noted by García-del-Hoyo et al. [40], the Observatory of Food Prices from the Spanish Ministry of Agriculture, Fisheries, and Food no longer collects pricing data for the retail sector. This time series expires in the final week of 2018. This made it necessary to employ a different data source for retail market prices that the Observatory of Food Prices collected. Therefore, a good proxy for the other variable is this new retail price that IDAPES is providing. In this regard, it should be noted that IDAPES is a trustworthy source. This statistical activity is included in the Andalusian Statistical and Cartographic Programmes from 2007 under the code 05.05.06 for ‘Analysis of prices of fishing products in retail establishments in Andalusia’ [57]. Both the Internet [58] and the website of the Andalusian information system on fishing trade and production (IDAPES) [59] are used to distribute the data. Every week, a panel of businesses divided into Supermarkets, Hypermarkets, and Fishmongers updates the data by grouping the products into commercial categories according to their size and place of origin. The weighted average series of all categories, supplied by IDAPES, has been utilised.

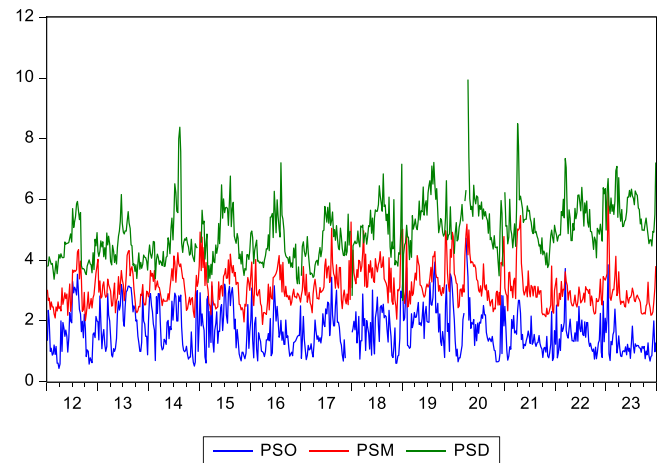


Fig. 9. Weekly price of fresh sardines in the first-hand sale market (PSO), wholesale market (PSM), and retail market (PSD). Prices are expressed in €/kg.³¹

Table 3 Summary of biweekly price data used in empirical estimation (before being log-transformed).

	Price in the first-hand sale market (PSO)	Price in the wholesale market (PSM)	Price in the retail market (PSD)
Mean	1.685591	3.130240	4.914728
Median	1.610000	3.020000	4.860000
Minimum	0.515000	2.190000	2.830000
Maximum	4.425000	5.530000	8.670000
Std. Dev.	0.645821	0.588311	0.838394
Coefficient of variation	38.31 %	18.79 %	17.06 %
Skewness	0.707953	0.939508	0.647746
Kurtosis	3.377307	4.055773	3.935967
Jarque-Bera	28.00241 ***	60.58319 ***	33.31279 ***

Note: *** Significant at the 1 % level.

** Significant at the 5 % level.

* Significant at the 10 % level.

and kurtosis coefficients are all more than 0 and 3, respectively, we observe positive skewness and excess kurtosis for all prices. The null hypothesis that the variable is normally distributed is rejected for all three prices at the 1 % significance level, based on the Jarque-Bera normality test.

Concerning the methodology, given that the objective of this study is to analyse the transmission of price volatility along the Spanish value chain of fresh sardines, we estimate two price volatility models: 1) a

conditional mean model using a VAR model [80], which analyses the behaviour of prices in levels, and 2) a conditional variance model using a MGARCH model [16,31], which analyses the price volatility of the residuals of the conditional mean model. Both models were estimated simultaneously using maximum likelihood procedures to achieve more efficient estimates than those provided by the two-step procedure [1,37,78] and more trustworthy statistical inference on the model parameters [88]. Student's t-distributed errors were used.

First, to find out if the prices are stationary, unit root and stationarity tests were undertaken. Next, as all the prices are stationary, the unrestricted VAR model, known as the conditional mean model, is specified including the three prices in the first-hand sale, wholesale, and retail markets of the fresh sardine value chain (PSO, PSM, and PSD). Then, we study volatility transmission along the value chain using the parametric generalised MGARCH model, also known as the conditional variance model. The Babba, Engle, Kraft, and Kroner (BEKK) model, first introduced by Engle and Kroner [32] and later generalised by Kroner and Ng [61], is used to specify the conditional variance model. It is defined as follows:

$$H_t = (C + Ed_t)(C + Ed_t)' + A'u_{t-1}u'_{t-1}A + B'H_{t-1}B + D'v_{t-1}v'_{t-1}D \quad (1)$$

where H_t is the conditional variance matrix of the error term in the VAR model; C represents a lower triangular matrix of constant coefficients; A represents a 3×3 matrix of parameters of ARCH terms, which displays the own and cross-transmission effects of the past shock; B represents a 3×3 matrix of parameters of GARCH terms, which shows the own and cross-transmission effects of past volatility; D is a 3×3 matrix that contains the asymmetric effects; E is a lower triangular matrix of constant coefficients; and d_t is a dummy variable that is equal to 1 in the fortnights in which the state of alarm was declared in Spain due to the COVID-19 pandemic, and 0 otherwise.⁴

Finally, it should be noted that to understand the dynamic structure of price level behaviour between the three markets of the value chain, Granger causality tests and impulse response functions are implemented. First, Granger causality tests are used to determine whether a variable can be explained by the lags of any other variables included in the system. Therefore, these tests allow us to identify temporal causal relationships between prices. Second, impulse response functions are analysed to show the short-run dynamic behaviour of the variables to the presence of transitory shocks. They provide the effects on the different variables of the system to positive shocks associated with the different time series. Thus, they indicate the sign, magnitude and persistence of the response of one variable to the impact on another.

³ There were some missing observations in the time series. Missing data in PSO were associated with weeks 2017:47, 2017:48, 2017:49, 2017:50, 2017:51, 2017:52; and 2020:13. Missing data in PSD were associated with weeks 2014:52, 2014:53, 2015:1, 2016:52, 2017:52, 2019:52, 2020:1, 2020:12, 2020:15, and 2020:53. The data for the first-hand sale and wholesale prices can be downloaded from [65]. The data for the retail prices can be downloaded from [59].

⁴ On March 14, 2020, the Spanish Government approved the declaration of a state of alarm throughout Spain to deal with the health emergency caused by COVID-19 disease (Royal Decree-Law 463/2020, of 14 March). The state of alarm was extended until 00:00 hours on June 21, 2020 (Royal Decree-Law 476/2020, of 27 March, Royal Decree-Law 487/2020, of 10 April, Royal Decree-Law 492/2020, of 24 April, Royal Decree-Law 514/2020, of 8 May, Royal Decree-Law 537/2020, of 22 May, Royal Decree-Law 555/2020, of 5 June). Subsequently, on October 25, 2020, the Spanish Government approved the declaration of a state of alarm throughout Spain again (Royal Decree-Law 926/2020, of 25 October). Its initial duration was until 00:00 hours on November 9, 2020 and was extended until 00:00 hours on May 9, 2021 (Royal Decree-Law 956/2020, of 3 November).

4. Results

As previously stated, the DF-GLS unit root test [30] confirmed that all three prices in the value chain are $I(0)$, or stationary.⁵ Next, according to the FPE (Final Prediction Error) and AIC (Akaike Information Criterion), four is the optimal number of lags for the VAR model, with eight being the maximum considered. Consequently, a VAR model of order four, denoted as VAR(4), was employed as the conditional mean model for the estimation.

The misspecification tests for the VAR(4) model are shown in Table 4. The multivariate autocorrelation test to ascertain whether the model residuals show ARCH effects [47], the multivariate autocorrelation test detailed by Lütkepohl [64], and Hosking's [49] multivariate autocorrelation test were undertaken. Additionally, we confirmed if the stability requirement is satisfied by the VAR(4) model. According to the results of both types of multivariate autocorrelation tests, we may conclude that the null hypothesis, which states that there is no multivariate autocorrelation in the VAR(4) model, is not rejected at a significance level of 5%. Consequently, the VAR(4) model has no residual autocorrelation. Furthermore, at a significance level of 1%, the null hypothesis, that there are no ARCH effects in the VAR model's residuals, is rejected. We may conclude that the MGARCH model should be used based on this result.

We then tested the three model prices for Granger causality. According to Table 5, log of price in the first-hand sale market (LPSO) is caused by log of price in the wholesale market (LPSM) at the 1% significance level and log of price in the retail market (LPSD) at the 1% significance level. Furthermore, LPSM is caused by LPSO at the 5% significance level and LPSD at the 1% significance level. Finally, LPSD is caused by LPSO at the 1% significance level and LPSM at the 1% significance level. Therefore, the results show that there are bidirectional causal relationships between all the prices of the value chain. This indicates the influence of prices of each market on prices of the other markets of the value chain. According to Sanjuán and Gil [77], these bidirectional causality relationships mean that each market uses information from the other market during the price setting procedure.

Thus, although the influence of the first-hand sale markets on the wholesale markets is significant, the effect of the wholesale markets on first-hand sale markets is more significant because of the influence they exert on wholesalers at the origin or on first-hand sale buyers. Additionally, the prices in first-hand sale and wholesale markets are also clearly influenced by the price in the retail market. This is because supermarkets are supplied mostly by imports and prices of imports are usually lower than first-hand sale and wholesale prices. Additionally, the share of imports in household consumption is almost 70% for sardines. However, wholesale market sales account for slightly more than half of apparent consumption of sardines in Spain. Finally, it should be noted that changes in fishers' supply will also have an influence on wholesale and retail markets.

As seen in Fig. 10, the impulse response functions were estimated to assess the short-term dynamic behaviour of prices and, consequently, ascertain how first-hand, wholesale, and retail prices would react over

Table 4
Multivariate tests for misspecification in the model.

Multivariate autocorrelation test $F_{Rao}(12)$	1.079411 (0.2853)
Hosking [49] multivariate test (12 lags)	77.67070 (0.30295)
Multivariate ARCH test (2 lags)	176.80 (0.00000)

Note: p-values are in parentheses.

⁵ The KPSS [62] stationarity test was undertaken, along with the augmented Dickey-Fuller [29], Phillips-Perron [73,74], and Ng-Perron [69] unit root tests.

Table 5
Granger causality tests.

Equation of the first-hand sale market	F statistic
LPSO is not Granger-caused by LPSM	18.34028***
LPSO is not Granger-caused by LPSD	16998.74555***
Equation of the wholesale market	F statistic
LPSM is not Granger-caused by LPSO	2.72918**
LPSM is not Granger-caused by LPSD	68.38244***
Equation of the retail market	F statistic
LPSD is not Granger-caused by LPSO	48.54428***
LPSD is not Granger-caused by LPSM	7.14013***

Note: *** Significant at the 1 % level.

** Significant at the 5 % level.

* Significant at the 10 % level.

time to unforeseen shocks at time t [11]. A shock produces only transitory effects on all prices. Consequently, within a few fortnights, all prices return to equilibrium. Specifically, a shock in the first-hand sale price has a similar impact on the wholesale and retail markets, with the former being somewhat more affected. This shock in the first-hand sale price has a temporary positive impact on the wholesale and retail prices. A shock in wholesale price has a small negative temporary effect on retail price. Nevertheless, it has a greater positive impact on first-hand sale price. Lastly, the shock in retail price has a similar effect on the first-hand sale and wholesale markets, with the former being somewhat more affected. This effect appears to fade quicker at the wholesale level than in the first-hand sale market.

The estimation of the asymmetric BEKK-MGARCH model is displayed in Table 6. A few misspecification tests are also included to make sure the model was appropriate for the data. According to the results, we may reject both the null hypothesis that all the coefficients in matrices A, B, and D as a whole are not significantly different from zero and the null hypothesis that all the coefficients in matrices A and B as a whole are not significantly different from zero at the 1 % significance level. These results indicate that the model may confirm time-varying volatility. Moreover, the null hypothesis that the coefficients in matrix D as a whole are not significantly different from zero is rejected at the 1 % significance level. As a result, the model asymmetric effects were verified to exist. Finally, we can accept the null hypothesis of Nyblom’s [70] joint stability test, which states that the model joint stability is assured at the 10 % significance level.

It should be mentioned that direct interpretation of the estimated BEKK-MGARCH model individual coefficients is not possible. However, the conditional variance equations in Table 7 provide some interesting findings. The coefficients accompanying $h_{i,j,t-1}$, $i, j = 1, 2, 3$ show how prices are affected by direct and indirect volatility transmission; the coefficients accompanying $u_{i,t-1}^2$ and $u_{i,t-1}u_{j,t-1}$, $i, j = 1, 2, 3$ indicate

how market shocks affect price volatility; and lastly, the coefficients accompanying $v_{i,t-1}^2$ and $v_{i,t-1}v_{j,t-1}$, $i, j = 1, 2, 3$ show how asymmetric market effects affect price volatility.

The results indicate that volatility in the first-hand sale market (h_{11}) is not explained by its own lags ($h_{11,t-1}$) or by past volatility in the prices of the wholesale market ($h_{22,t-1}$) or the retail market ($h_{33,t-1}$). Furthermore, none of the coefficients accompanying the covariance terms are significant. Additionally, volatility in the wholesale market (h_{22}) is explained by its own lags ($h_{22,t-1}$), but it is not explained by past volatility in the prices of the first-hand sale market ($h_{11,t-1}$) or the retail market ($h_{33,t-1}$). However, the parameter which accompanies $h_{23,t-1}$ differs significantly from zero. Consequently, this correlation between the wholesale and retail markets ($h_{23,t-1}$) may decrease wholesale price volatility if both prices move in the same direction. Finally, volatility in the retail market (h_{33}) is explained by past volatility in wholesale prices ($h_{22,t-1}$), but it is not explained by its own lags ($h_{33,t-1}$) or by past volatility in first-hand sale prices ($h_{11,t-1}$). Moreover, none of the coefficients accompanying the covariance terms are significant.

Regarding market shocks, past shocks in the first-hand sale market ($u_{1,t-1}^2$) and in the wholesale market ($u_{2,t-1}^2$) are not significant in explaining any variances in the markets considered. However, past shocks in the retail market ($u_{3,t-1}^2$) seem to increase the retail variance (h_{33}). Additionally, the coefficient which accompanies $u_{2,t-1}u_{3,t-1}$ is significant in the conditional first-hand sale variance (h_{11}) equation. Additionally, the coefficient which accompanies $u_{1,t-1}u_{2,t-1}$ is significant in the conditional wholesale variance (h_{22}) equation.

Concerning the asymmetries in price volatility, asymmetric effects are only found to be significant for first-hand sale price volatility. Past shocks to the first-hand sale market ($v_{1,t-1}^2$) and wholesale market ($v_{2,t-1}^2$) are found to have an asymmetric effect on first-hand sale price volatility (h_{11}). This suggests that when there are negative shocks to its variance, price instability may somewhat increase. Additionally, wholesale price decreases appear to have a greater impact on first-hand sale prices than do price rises. Finally, the volatility of the first-hand sale market (h_{11}) is also affected by the asymmetric effect of the covariance term ($v_{1,t-1}v_{2,t-1}$).

The predicted volatility in each of the three markets within Spain’s fresh sardine value chain is depicted in Fig. 11. It is worth noting that the first-hand sale market exhibits the highest level of volatility, with the wholesale and retail markets following suit. Other research on volatility price transmission along the value chain have also seen this phenomenon [38,40]. Furthermore, sardine prices in Spain exhibit less volatility in the retail market than they do in the first-hand sale or wholesale markets of the value chain, according to Guillen and Franquesa [43]. Thus, a similar conclusion is drawn. Specifically, the retail market exhibits some rigidity, and therefore price volatility in the wholesale and

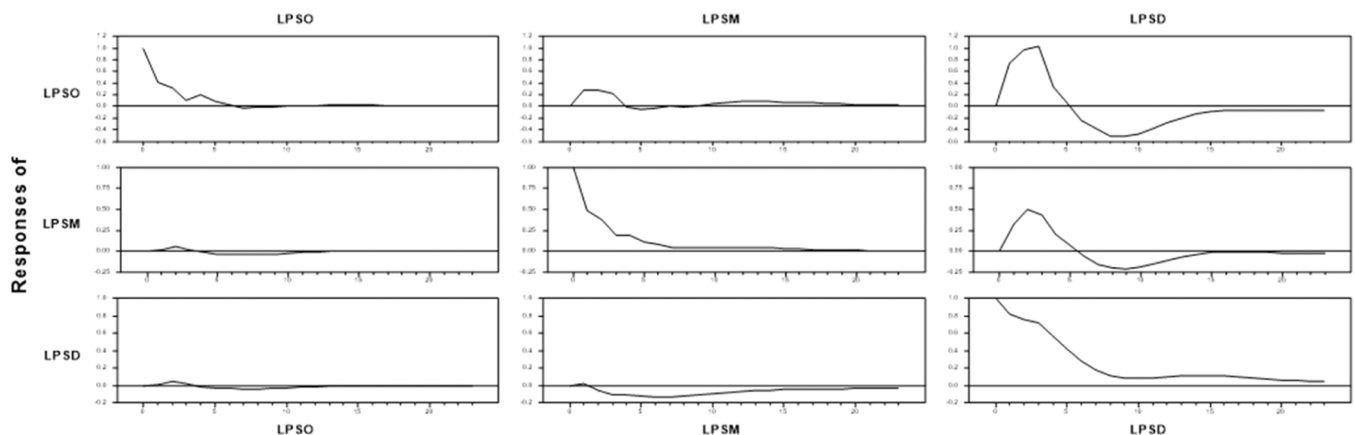


Fig. 10. Impulse response functions of prices. Note: The abscissa axes represent the 24-fortnight time horizon, and the ordinate axes show the response of prices to an orthogonal shock at another price along the value chain.

Table 6
Asymmetric BEKK-MGARCH(1,1) estimation: First-hand sale market - Wholesale market - Retail market.

$$H_t = (C + Ed_t)(C + Ed_t)' + A'u_{t-1}u_{t-1}'A + B'H_{t-1}B + Dv_{t-1}v_{t-1}'D$$

$$C = \begin{pmatrix} c_{11} & 0 & 0 \\ c_{21} & c_{22} & 0 \\ c_{31} & c_{32} & c_{33} \end{pmatrix}, A = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}, B = \begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{pmatrix}, D = \begin{pmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{pmatrix} E = \begin{pmatrix} e_{11} & 0 & 0 \\ e_{21} & e_{22} & 0 \\ e_{31} & e_{32} & e_{33} \end{pmatrix}$$

	i = 1	i = 2	i = 3
c_{11}	0.218860306***		
c_{21}	0.075695649***	0.042839955 * **	
c_{31}	0.041852030***	-0.043193529 * **	0.022063517 *
a_{11}	0.106368088	0.149673916 * **	-0.014908730
a_{21}	0.511458703**	0.276146571 * **	-0.116623277
a_{31}	0.661039837***	0.001233943	0.573404878 * **
b_{11}	0.342272563**	-0.014343718	-0.072588797 *
b_{21}	-0.353947877	0.519411529 * **	0.416724403 * **
b_{31}	0.518608900	-0.513969435 * **	-0.252801064
d_{11}	1.135672098***	0.106319480 *	0.031518130
d_{21}	-2.503443329***	-0.067327594	-0.019147173
d_{31}	-0.271019950	-0.401470198 * *	-0.149068498
e_{11}	-0.000728787		
e_{21}	0.077316202*	-0.080955762	
e_{31}	0.093998882**	0.112814182 * *	-0.012395755
Shape(t degrees)			7.327451425 * **
LR test for the null hypothesis of joint significance of parameters of matrices A, B, D			25.07631 * **
LR test for the null hypothesis of joint significance of parameters of matrices A, B			24.60123 * **
LR test for the null hypothesis of asymmetric effects			5.84530 * **
Nyblom [70] joint stability test			12.9367731 (0.55)

Notes: The Nyblom test is shown with its p-value in parentheses.

*** Significant at the 1 % level.

** Significant at the 5 % level.

* Significant at the 10 % level.

first-hand sale markets of the value chain is only slightly transmitted to the retail market.

5. Conclusions

This article studies the price volatility transmission mechanism of the fresh European sardine (*Sardina pilchardus*) supply chain in Spain. Consequently, it excludes other species of sardines that are only utilised in the processing sector and are not imported fresh. Sardine fishing is a significant industry in Spain's coastal regions and is a fishing species with cultural and culinary importance. Sardine landings in Spain have historically been very significant, representing more than 20 % of total

fishery landings until 1945. Thereafter, they have progressively decreased, but they have been always above 10 %. There has been a recovery of its relative importance from 1978, with the development of a powerful canning and reduction industry in the Canary Islands. They have reached a peak in 1984 when sardine landings accounted for 29.6 % of the total fishery landings with 313,455 mt, of which 145,847 mt come from the waters of the Northeast Atlantic and the Mediterranean. Since 1999, when the southern Moroccan fishing grounds were closed to the Canary Islands fleet, sardine landings - now largely limited to the Northeast Atlantic and Mediterranean waters - have been losing importance, going from 7.7 % in 2000, to 6.1 % in 2010 and 3.4 % in 2023, with only 30,011 mt. landed. Considering this supply of sardine landed by the Spanish fleet, imports, exports, and consumption by the processing industry, the apparent supply in the fresh market has been approximately 26,312 mt in 2023. It should be noted that price transmission along Spain's fresh sardine value chain has been studied by Guillen and Franquesa [43]. This is the first investigation of how price volatility is transmitted throughout this fishing product value chain.

Using biweekly price data from 2012 to 2023, we estimate a multivariate VAR(4) model for the conditional mean model, and an asymmetric BEKK-MGARCH(1,1) model for the conditional variance model. In addition to allowing asymmetries in the transmission mechanism along the value chain, the conditional variance model allows us to study the transmission of price volatility between the various levels of the value chain and the interactions between them.

It is worth highlighting that among the products examined by Dahl and Oglend [24], the group of pelagic species that do not include tuna - whose supply is derived only from fishing - has the largest volatility. As a result, the findings of this investigation - namely, the presence of ARCH effects in the VAR model residuals - are coherent.

The BEKK-MGARCH model shows that price volatility changes over time and reacts differently to market shocks. The retail market is the least volatile, followed by the wholesale market, while the first-hand sale market is the most volatile due to fluctuations in catches. Consumers experience minimal price volatility in the first-hand sale and wholesale markets. The model also reveals that past market shocks affect price volatility differently, with decreases in wholesale prices having a greater impact on first-hand sale prices than increases. This asymmetry may be due to the availability of alternative pelagic fish such as anchovy in the wholesale market and strong imports when first-hand sale prices rise. Additionally, the high concentration of players in the wholesale market contributes to these effects.

These asymmetric impacts suggest that there is some degree of imperfect market efficiency. Thus, it is not possible to instantaneously incorporate information from one value chain market into another or

Table 7
Conditional variance equations: First-hand sale market - Wholesale market - Retail market.

Case in which the dummy variable \bar{d}_t is equal to 0		
h_{11}	$= 0.0479^{***} + 0.0113u_{1,t-1}^2 + 0.2616u_{2,t-1}^2 + 0.4370u_{3,t-1}^2 + 0.1088u_{1,t-1}u_{2,t-1} + 0.1406u_{1,t-1}u_{3,t-1} + 0.6762^*u_{2,t-1}u_{3,t-1} + 1.2898^{***}v_{1,t-1}^2 + 6.2672^{**}v_{2,t-1}^2 + 0.0735v_{3,t-1}^2 - 5.6862^{**}v_{1,t-1}v_{2,t-1} - 0.6156v_{1,t-1}v_{3,t-1} + 1.3570v_{2,t-1}v_{3,t-1} + 0.1172h_{11,t-1} + 0.1253h_{22,t-1} + 0.2690h_{33,t-1} - 0.2423h_{12,t-1} + 0.3550h_{13,t-1} - 0.3671h_{23,t-1}$	
h_{22}	$= 0.0076^{***} + 0.0224u_{1,t-1}^2 + 0.0763u_{2,t-1}^2 + 0.00002u_{3,t-1}^2 + 0.0827^{***}u_{1,t-1}u_{2,t-1} + 0.0004u_{1,t-1}u_{3,t-1} + 0.0007u_{2,t-1}u_{3,t-1} + 0.0113v_{1,t-1}^2 + 0.0045v_{2,t-1}^2 + 0.1612v_{3,t-1}^2 - 0.0143v_{1,t-1}v_{2,t-1} - 0.0854v_{1,t-1}v_{3,t-1} + 0.0541v_{2,t-1}v_{3,t-1} + 0.0002h_{11,t-1} + 0.2698^{**}h_{22,t-1} + 0.2642h_{33,t-1} - 0.0149h_{12,t-1} + 0.0147h_{13,t-1} - 0.5339^{***}h_{23,t-1}$	
h_{33}	$= 0.0041^{***} + 0.0002u_{1,t-1}^2 + 0.0136u_{2,t-1}^2 + 0.3288^{***}u_{3,t-1}^2 + 0.0035u_{1,t-1}u_{2,t-1} - 0.0171u_{1,t-1}u_{3,t-1} - 0.1337u_{2,t-1}u_{3,t-1} + 0.0010v_{1,t-1}^2 + 0.0004v_{2,t-1}^2 + 0.0222v_{3,t-1}^2 - 0.0012v_{1,t-1}v_{2,t-1} - 0.0094v_{1,t-1}v_{3,t-1} + 0.0057v_{2,t-1}v_{3,t-1} + 0.0053h_{11,t-1} + 0.1737^*h_{22,t-1} + 0.0639h_{33,t-1} - 0.0605h_{12,t-1} + 0.0367h_{13,t-1} - 0.2107h_{23,t-1}$	
Case in which the dummy variable \bar{d}_t is equal to 1		
h_{11}	$= 0.0476 + 0.0113u_{1,t-1}^2 + 0.2616u_{2,t-1}^2 + 0.4370u_{3,t-1}^2 + 0.1088u_{1,t-1}u_{2,t-1} + 0.1406u_{1,t-1}u_{3,t-1} + 0.6762^*u_{2,t-1}u_{3,t-1} + 1.2898^{***}v_{1,t-1}^2 + 6.2672^{**}v_{2,t-1}^2 + 0.0735v_{3,t-1}^2 - 5.6862^{**}v_{1,t-1}v_{2,t-1} - 0.6156v_{1,t-1}v_{3,t-1} + 1.3570v_{2,t-1}v_{3,t-1} + 0.1172h_{11,t-1} + 0.1253h_{22,t-1} + 0.2690h_{33,t-1} - 0.2423h_{12,t-1} + 0.3550h_{13,t-1} - 0.3671h_{23,t-1}$	
h_{22}	$= 0.0249^* + 0.0224u_{1,t-1}^2 + 0.0763u_{2,t-1}^2 + 0.00002u_{3,t-1}^2 + 0.0827^{***}u_{1,t-1}u_{2,t-1} + 0.0004u_{1,t-1}u_{3,t-1} + 0.0007u_{2,t-1}u_{3,t-1} + 0.0113v_{1,t-1}^2 + 0.0045v_{2,t-1}^2 + 0.1612v_{3,t-1}^2 - 0.0143v_{1,t-1}v_{2,t-1} - 0.0854v_{1,t-1}v_{3,t-1} + 0.0541v_{2,t-1}v_{3,t-1} + 0.0002h_{11,t-1} + 0.2698^{**}h_{22,t-1} + 0.2642h_{33,t-1} - 0.0149h_{12,t-1} + 0.0147h_{13,t-1} - 0.5339^{***}h_{23,t-1}$	
h_{33}	$= 0.0234^* + 0.0002u_{1,t-1}^2 + 0.0136u_{2,t-1}^2 + 0.3288^{***}u_{3,t-1}^2 + 0.0035u_{1,t-1}u_{2,t-1} - 0.0171u_{1,t-1}u_{3,t-1} - 0.1337u_{2,t-1}u_{3,t-1} + 0.0010v_{1,t-1}^2 + 0.0004v_{2,t-1}^2 + 0.0222v_{3,t-1}^2 - 0.0012v_{1,t-1}v_{2,t-1} - 0.0094v_{1,t-1}v_{3,t-1} + 0.0057v_{2,t-1}v_{3,t-1} + 0.0053h_{11,t-1} + 0.1737^*h_{22,t-1} + 0.0639h_{33,t-1} - 0.0605h_{12,t-1} + 0.0367h_{13,t-1} - 0.2107h_{23,t-1}$	

Notes: h_{11} is the variance of the first-hand sale market, h_{22} is the variance of the wholesale market, and h_{33} is the variance of the retail market.

** Significant at the 1 % level.

* Significant at the 5 % level.

* Significant at the 10 % level.

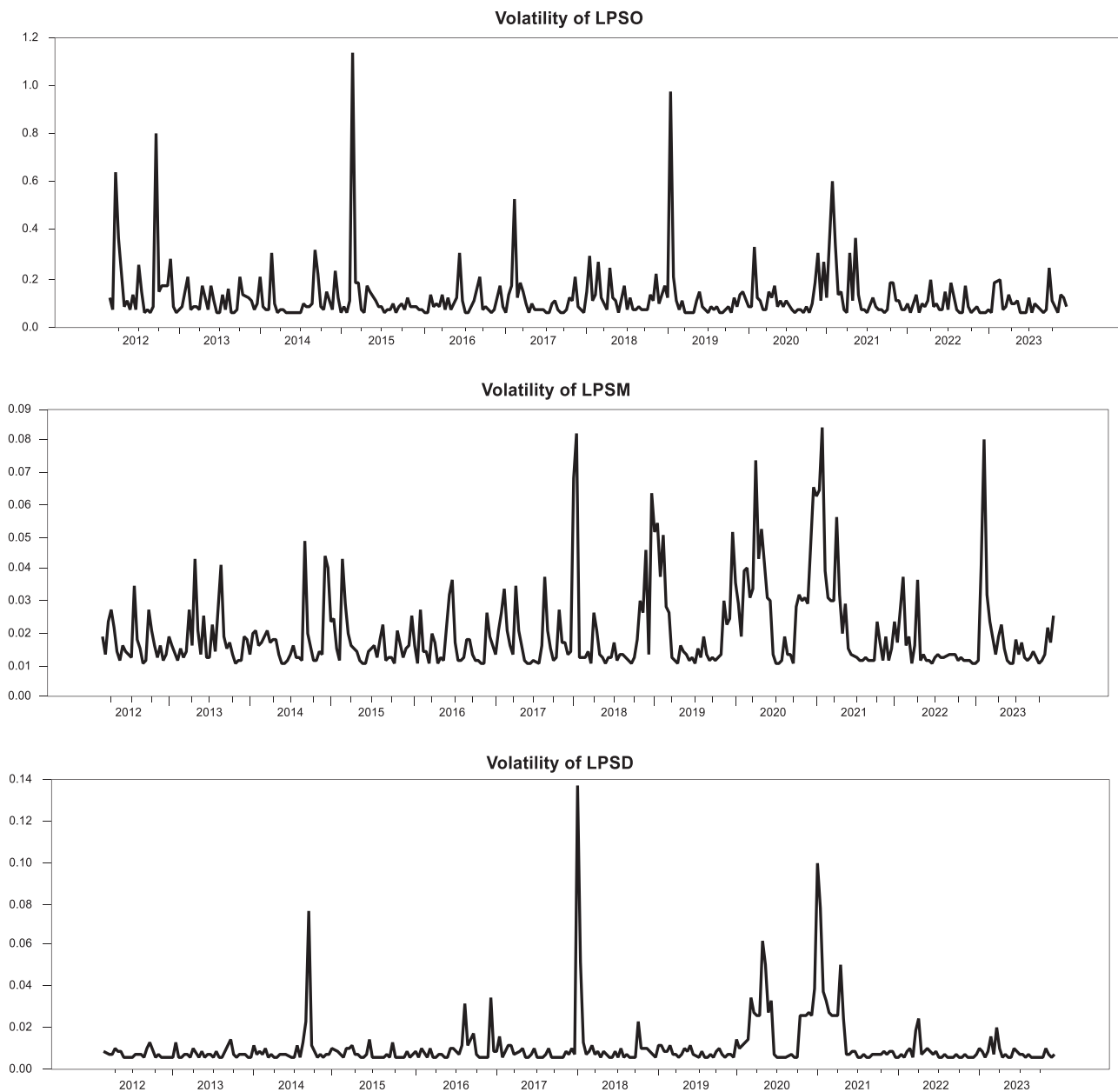


Fig. 11. Predicted conditional variances.

vice versa. Any shock would be dissipated by efficient markets with a non-persistent effect on volatility [18,38].

In the wholesale market, landings of sardines auctioned at Spanish first hand-sale markets and imports from different origins come together simultaneously. Unlike other pelagic species such as anchovies [40] in which imports occur mainly during periods of reduced supply at first-hand sale markets, in the case of sardines they correspond to periods in which the first hand-sale supply is significant, helping to stabilise wholesale prices by reducing volatility. The monthly series of fresh sardine imports actually shows a high correlation with household purchases, especially in supermarkets, which does not occur in the case of anchovies. Thus, the periods of greatest volatility in the wholesale market coincide with reductions in first hand-sale supply and imports simultaneously (end of summer 2014, beginning of 2015, end of 2017 or end of 2019) and, above all, in the periods of maximum incidence of COVID-19 pandemic. It is precisely in these periods that increases in volatility in wholesale markets are transmitted to a greater extent to retail markets, especially in supermarkets, which carry out large

imports. However, the volatility caused by increases in supply and price reductions at first hand-sale markets is not transmitted significantly to the wholesale and retail markets (March–April 2012; September 2012).

Similarly, according to Buguk et al. [18] and Ferrer-Pérez and García-de-Rentería [38], these asymmetries lead us to the conclusion that the wholesale market in the value chain exerts market power. Consequently, this leads to a lack of transparency in the formation of prices and possible unfair business practices and anti-competitive actions that stifle competition and distort the market.

According to Pincinato et al. [75], a rise in price volatility indicates higher expenses and risks related to fishing, which negatively impacts the fishing industry capacity to maintain a stable revenue stream. Reducing volatility in the sardine value chain generally and in the first-hand sale market specifically would be desirable to prevent fishers from decreasing their investment in fishing activity, as the majority of them are risk-averse [48,75,81]. Therefore, steps to diminish volatility should be done.

First, as pointed out by Dahl [21], since the supply is more stable,

aquaculture lowers price volatility. However, to date, despite multiple attempts in research centres in the ICES IXa area, technologies have not yet been developed to complete the breeding and fattening cycle of European sardines in a profitable way. The main bottleneck is the availability of suitable feed for mass production at an adequate cost [51, 76].

Second, according to Pincinato et al. [75], as it would reduce price swings caused by variations in their supply, market integration with other fish species have to be taken into account. As pointed out by Tveteras et al. [86], pelagic fisheries have a highly integrated market. Consequently, this would help to decrease the volatility of sardine prices.

Third, the management of fisheries can be enhanced. Effective fishery management, according to Pincinato et al. [75], allows people more control over their catches, which leads to more consistent revenue as well as healthier fish stocks and higher-quality fish. According to the 2013 reform of the European Union Common Fisheries Policy, fishing sustainably would also facilitate to obtain stable prices under transparent conditions, clearly benefiting consumers. To do this, it is critical to continue managing the resource sustainably because it will increase sardine supply stability and enhance price stability.

It should be mentioned that fisheries in ICES area IXa South (Gulf of Cádiz) are subject to transferable quotas and TAC, in contrast to fisheries in ICES area VIIIb,c. Fishers determine the effective length of the season based on when they anticipate higher prices. Regulating the Spanish fleet in ICES area IXa South (Gulf of Cádiz) since 2018, the system of individual transferable quotas unfortunately prevents information about the prices at which these quotas are sold from being obtained. Fishers are only obligated to disclose the quantities transferred and, as a result, the quota selling price is not reported. Consequently, we are unable to analyse the potential interactions between the quota and product markets.

To further ensure sustainability consistent with mild price volatility, initiatives to build a more dynamic, transparent, and simple system of fishing quotas should be promoted [38]. This involves a system of quota exchanges that can enhance fish supply and maintain price stability in hard times. As a result, future developments are anticipated in the areas of price stability and fish supply. It is challenging to expand this management system to the Bay of Biscay and, more importantly, the Mediterranean fleet, in which effort constraints are used for management.

Other policy recommendations can include raising fishing fleet productivity and creating more favourable financial assistance and access to technology advancements (especially for small-scale agents). Better management can, however, only partially offset the consequences of increased natural variability, even while it can successfully reduce harvest and price volatility [75].

Lastly, the sardine value chain should have more market transparency. More competitiveness and improved resistance to price volatility can be achieved through more transparency in the fresh sardine supply chain. As demonstrated in this paper, the numerous middlemen in the Spanish food value chain contribute to the high degree of complexity in the sardine value chain [38]. This can lead to asymmetries in the price formation process by making it unstable and opaque at times. Thus, it is anticipated that this measure will lessen price volatility. Offering higher-quality fish products with complete traceability can be facilitated by improving the application of quality-differentiated marketing tactics with quality labelling. This may guarantee transparency, increase consumers' added value, and provide wholesalers and retailers with greater legitimacy. Therefore, it might help the fresh sardine value chain become more transparent. It should be mentioned that the law of the food value chain has been changed to create more transparent, egalitarian, and balanced trade relations in Spain (Law 16/2021 of 14 December, which amended Law 12/2013 of 2 August).

Furthermore, it is necessary to take into account the impact of the Andalusian regional government's planned set-up of an online sales platform for fishing products on price volatility [45,46]. Similarly, it is

important to consider how climate change may affect the price volatility of small pelagic species like sardines, which is determined by landing variability [75].

Finally, we would like to draw attention to a few informational limitations of the study. First, a certain quantity of sardines is not sold throughout the basic value chain first-hand sale market – wholesaler – retailer. Other alternative value chains are becoming more significant. These include small local businesses that purchase from the first-hand sale markets, and retail supermarket chains that import directly or purchase directly from the first-hand sale markets. Second, sardine retail prices for Andalusia as a whole is the time series used to represent retail market prices. Up to 2018, its pattern was strikingly identical to the retail prices given by Ministry of Agriculture, Fisheries, and Food. As a result, there might have been slight distortions in the results obtained. Third, imported sardines play a significant role in the Spanish seafood market, catering to a specific segment. The omission of import prices from the analysis could potentially affect the accuracy of the estimation because import prices may have a significant relationship with other prices in the markets of the value chain. However, it should be noted that although imports are relevant, their relative importance has decreased. In 2019, they accounted for 80 % of the supply, whereas nowadays they barely exceed 40 % as the stock in the ICES subdivision IXa has recovered. Most of them are sold in the MERCASA wholesale network, and therefore, they are already considered indirectly.

CRediT authorship contribution statement

Ramón Jiménez-Toribio: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Juan José García-del-Hoyo:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization.

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Data availability

The data will be available in the Arias Montano repository at the University of Huelva.

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