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Granger causality between the canning sector and the Spanish tuna fleet: Evidence from the Toda-Yamamoto approach

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ABSTRACT

In this paper, we provide an overview of the Spanish fish processing sector in general, and, specifically looking at canned tuna. We study the evolution of the Spanish freezer tuna fleet, shipowning companies and joint ventures in third countries, and the fleet interaction with the canned tuna processing sector. The evolution of canned tuna industry and its market in Spain over time are described and important variables such as production, consumption, imports and exports of canned tuna are presented. The policy measures related to the development of the Spanish tuna industry and the freezer tuna fishing fleet are presented. In spite of the globalisation process, this industry is still one of the most important worldwide and has survived unlike all European countries. Interesting findings are shown about the situation of the sector using several statistics and econometrics techniques to obtain a graph which allow us to understand the interrelationships between its main variables in depth. In conclusion, the canning industry with its production, foreign trade and domestic consumption play a key role in explaining the dynamics of the sector and the high demand of canned tuna causes the expansion of the fleet.

1. Introduction

The Spanish canning tradition, which began in the first half of the 19th century, was initially focused on the production of canned sardines, although the huge catches of bluefin tuna obtained by tuna traps in some specific areas, such as the Gulf of Cádiz, have been the base of a powerful processing sector oriented to the export of canned bluefin tuna since the 1880s. These exports accounted for between 30% and 50% of the canning production of Huelva and Cádiz during the first two decades of the 20th century. However, despite the fact that this activity continued until the early 1970s, it was limited by the catches of Andalusian tuna traps. As a matter of fact, around 1960 the production of canned tuna barely represented 6% of Spanish canning production, with just over 3 million kg per year. On the other hand, from 1964 onwards, huge quantities of tropical tuna began to be landed. This tropical tuna was caught by a modern fleet that began to operate in the waters of the Eastern Central Atlantic. Additionally, the processing sector began a process of reconversion, whose productive activity was based on these new resources. Consequently, in 1966 the specific weight of canned tuna in the production of the canning sector doubled and later it maintained its expansion in the following decades: 25% in 1979, 50% in 1992 and almost 68% of Spanish canning production nowadays.

In the international context, the Spanish production of canned tuna currently stands at around 283 million kg, representing 70.1% of EU production and 14.1% of the world total. As a result, Spain is the second producing country, behind Thailand and ahead of Ecuador, Iran, the United States and Indonesia. These six countries account for almost 75% of world production of canned tuna, where Italy, the Philippines and Mexico also stand out. Spain is not only one of the main producing countries, but it is also one of the main consumers because apparent consumption currently stands at about 327 million kg, representing 44.4% of the EU total consumption and 16% of the world total[1].

Although these figures are already significant, the importance that this product has in the Spaniards' diet is supported by reaching a per capita consumption of about 7 kg per inhabitant per year, representing eight times the average consumption of the remaining EU countries and about seven times the world average. As a matter of fact, Spain leads the consumption per inhabitant and year among the main producers, followed by Thailand with 6 kg per inhabitant and year and, by far, by Italy, which is the second consumer in the EU, with 2.75 kg per inhabitant and year.

Not only is the production of canned tuna relevant, Spain is also a

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[1] For the purposes of comparison, we have used FAO statistics, and apparent consumption has been estimated as the sum of production and imports, minus exports.

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world power in tuna catches. Its catches are more than 324 million kg, of which 275 million kg corresponds to tropical tuna caught by a freezer tuna fleet. This fleet is currently made up of 27 purse-seiners with a medium tonnage over 2700 GT, which represents 8% of the world fleet. Furthermore, adding these to the fleet controlled by Spanish companies with third country flags, they total 53 large tuna vessels, representing 13% of the world fleet [24].

It is also the only long-distance fishing segment whose specific weight has grown over the last two decades. If in 2006, it accounted for 16.3% of the total tonnage of the Spanish fishing sector, nowadays it represents more than 22%. The activity of this fleet is shown in the Spanish catches of tropical tuna, especially in the Indian Ocean, also in the Eastern Central Atlantic and in the Pacific, which are 5.8% of the world total, and more than 80% of the catches of these species in the whole of the EU.

The analysis of the evolution of these productive sectors in Spain and its international contextualisation are the main objective of this work. To do it, the basic variables for this are determined, some of them being related to policy for the development of the Spanish tuna industry and fleet. Next, interrelationships are described and causal relationships between them are evaluated. Thus, we start making a brief reference to historical evolution, which allows us to establish the context in which these variables are developed, we describe the statistical sources used to build the necessary time series and the methodological foundations of the techniques implemented. In particular, we use econometric techniques to analyse causality in the Granger [19] sense using time series and the standard procedures suggested in the literature [41]. Also, we make use of statistical techniques such as bivariate correlations and partial correlations. Finally, we present the results and discuss them taking into account the possible policy impacts associated with those variables.

2. Canned tuna and tuna fleet in Spain

2.1. Background

As we have mentioned above, the catches of bluefin tuna (*Thunnus thynus*) in the south of the Iberian Peninsula have an ancestral character. Their processing is attested by the archaeological deposits of salting factories located throughout the coast and different classical texts [3, 18]. This activity was maintained, to a lesser extent, during the Middle Ages [15,33] and it intensified from the 13th century. The catches were made by “almadrabas de tiro” (i.e., trawling nets), which have been well described since ancient times [11,37]. Their use extended until the beginning of the 19th century, when they were completely replaced, not without problems, by “almadrabas de buche” (i.e., traps of craw), which are similar to the current ones [14,36], the first being set in El Terrón (Huelva) in the middle of the 18th century [34]. During this time, especially during the 16th century, tuna catches in traps were spectacular. They enriched the Ducal House and they became an export product to the Italian market - in brine and salted - and they were also sold inside the peninsula. After the liberalisation of the sector, the exploitation of tuna traps is carried out by administrative concessions for 2, 5 or 10 years. But in the 1870s, due to bad fishing seasons in the Sicilian tuna traps, which were unable to meet the demand of the Italian market, some Italian entrepreneurs settle in Cádiz and, as a result, the first canning factories begin to develop and produce both vacuum sterilised canned fish and canned fish in oil or in brine in wooden barrels [16,39]. They are not the first Spanish canning factories because there are small factories in the Bay of Biscay and Galicia from the 1830s [4,25]. They were not very specialised and had a small size. Tuna is merely symbolic in their canned fish products, although they began to process huge amounts of albacore or Northern bonito (*Thunnus alalunga*).

The role of Italian entrepreneurs in the development of canned tuna in the Gulf of Cádiz came to an end soon. By 1888, the tuna trap businessmen from Isla Cristina and Ayamonte had not only started to expand their businesses, but they also began to take control of the tuna traps in Cádiz and, in addition, of the emerging associated canning industry. Therefore, the tuna trap-canning complex, which aimed to catch and manufacture canned tuna destined for the foreign market (Italy and, to a lesser extent, France, England and Latin America), practically maintained its exclusivity in the production of canned tuna until the mid-1960s, with the exception of processed Northern bonito (*Thunnus alalunga*) in the Basque Country, which also started at the end of the 19th century, and tunas, in general, in the Canary Islands, whose development began in the 1930s. In addition, in 1928, in Primo de Rivera’s dictatorship, the National tuna trap Consortium was set up. It grouped the tuna trap licensees, who contributed their licences, assets, ships and factories. This way, until its disappearance in 1972, most of the catches of bluefin tuna and canned production were based on these, they were monopolised and they were processed in their factories, using the catches of tuna traps and catches by its own ships in the Canary Islands.

Meanwhile, the canning sector in the rest of Spain is concentrated on other productions: sardine in Galicia and bonito and anchovy in the Bay of Biscay, without rejecting other species of fish (mackerel, frigate tuna), molluscs and crustaceans. The factories of the ports in the Gulf of Cádiz that were not included in the Consortium also had to guide their activity to the processing of sardine, mackerel, frigate tuna, anchovy and cockle from 1928. Before, traps used to auction a part of their production in the first-hand sale markets and, consequently, they helped the whole sector to have access to raw material. From 1963, when the expansion of the freezer tuna fleet begins, two fundamental events occur. Firstly, the massive production of canned tuna other than bluefin tuna begins in all the Spanish coast and, in addition, it coincides with the collapse of trap catches. As it was not possible to increase the price because of the shortage of raw material, there was a collapse of profits in the Consortium and its liquidation happened in 1972. The subsequent history of the Andalusian traps will be actually linked to the sale of fresh or frozen bluefin tuna destined for the Japanese market.

2.2. Fishing for tropical tuna

Although significant catches of tuna have occurred in the Canary Islands from the late 19th century, the expansion of these tuna catches occurs in the 1920s. As a result, an emerging salting industry appeared. However, it went into crisis in 1930–1931 [7,8]. After the Spanish Civil War (1936–1939) the first canning factories became established, but the local fleet is unable to supply its production continuously due to its small size. In the mid-1950s, the Canarian canneries began hiring live bait bonito boats from the Basque Country, which were not in use after the end of the Northern bonito or albacore (*Thunnus alalunga*) campaign to go on fishing in West African waters [13]. These boats had already worked in the Gulf of Cádiz some years before and contributed to the overexploitation of bluefin tuna [5]. This fleet was supplied with the bait in the waters of “Rio de Oro” (Spanish for Gold River) and went fishing for skipjack tuna (*Katsuwonus pelamis*) and, to a lesser extent, yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*) in the waters between Cabo Blanco (or Cap Blanc in French) and the Gulf of Guinea [40]. In 1960, North American canning companies hired these vessels for their supply. Although it meant a ruinous business, it aroused interest in some shipowners to build new vessels, but they used purse-seine gear with on-board freezing systems. The first company that tried to devote to tropical tuna fishing with purse seine gear was P.E.S.C.A.T.U.N. from Vigo which, in 1956, launched two live bait ships for this fishery. Nonetheless, that first experience was a failure because one of the ships sank when it reached the fishing ground and the yields were not as expected. For this reason, the second of them, "Marinero", was converted into a purse seiner between 1958 and 1961, being the first Spanish

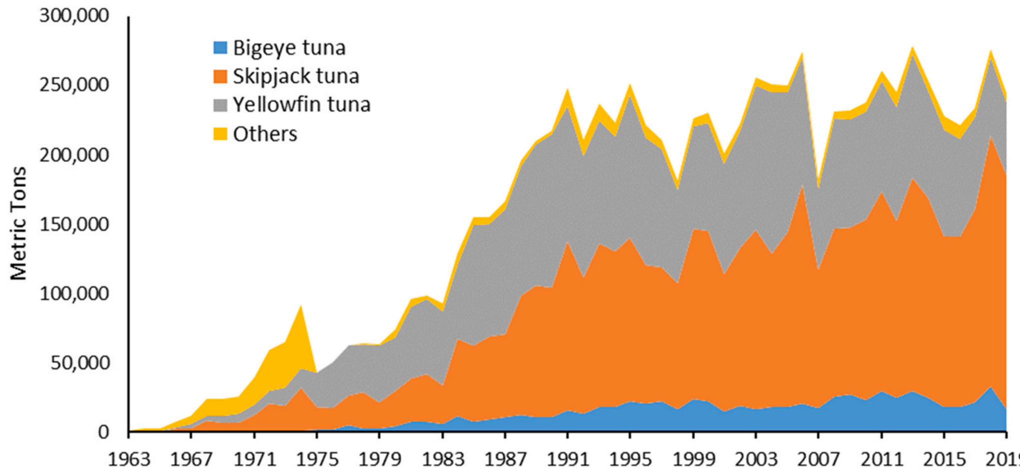

Fig. 1. Catches of large tuna by the Spanish tuna fleet of purse-seine freezer vessels (1963–2019).

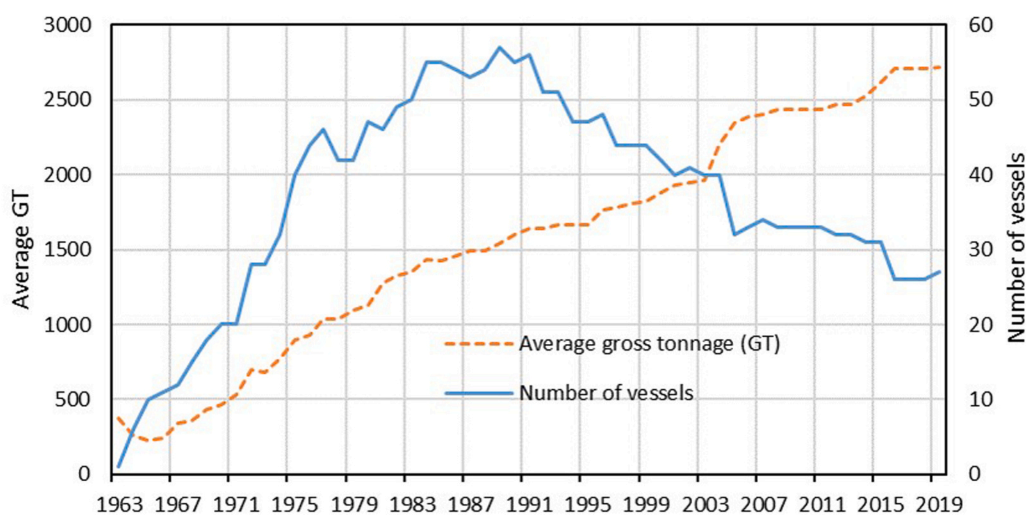

Fig. 2. Evolution of the number of vessels and the average tonnage (GT) of the Spanish freezer tuna fleet (1963–2019).

freezer vessel to fish with purse seine gear. It was acquired in 1962 by PESCANOVA, which also used two of its vessels as purse seiners - "Eo" and "Lerez" - although it would soon dedicate them to trawling[2].

These initiatives, which were more or less successful, were enough for some shipowners from Bermeo, followed by Galician and Andalusian shipowners, to consider the possibility of changing their activity into modern freezer purse-seiners. This started the expansion of a fleet segment that nowadays is the only one in which the distant-water fleet maintains its activity on a scale which is similar to the greatest years of Spanish fishing. The first vessels built by the Basque shipowners were "Atunero Primero" of 372 GT from Pasajes in 1963 and "Arene", "Artza" and "Atalde" (all three with 183 GT), "Playa de Baquio" (258 GT) and "Cimarrón" (renamed "Algeciras") of 379 GT in the following year[3]. These vessels, and those that later join them, began to operate in waters close to the Gulf of Guinea and West African fishing grounds. However, they expanded their activity to the Indian Ocean in 1984 and, finally, to the Pacific Ocean from 1998. Overall, in 2019 the Spanish fleet catches were 243,794 MT, of which 71.4% corresponded to the Indian Ocean and 24.4% to the waters near West Africa. Most of the catches (69%) are skipjack tuna (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*) - which represents 21.7% - and bigeye tuna (*Thunnus obesus*) with 6.9%, corresponding the rest to other species (see Fig. 1).

The first tuna freezer purse seiners were small-sized in the interval 180-380 GT, commissioned by individual entrepreneurs. They were mostly live bait vessel owners who were already operating in the Eastern Central Atlantic Ocean. However, given the enormous profitability of

[2] The first freezer purse-seiner dedicated to tropical tuna fishing in the Eastern Central Atlantic was the North American "May Queen", which carried out a campaign between 1960 and 1962. It was followed in 1961 by the French "Curlinka", which was a former Basque-French clipper. "Curlinka" had participated in the first Dakar campaigns [13,43].

[3] Thus, in 1964 there were 6 freezer tuna vessels that displaced 1558 GT. In 1970 the fleet was already made up of 20 vessels and 9242 GT. In 1975 it was made up of 40 vessels with 35,940 GT. In 1980 it increased to 47 ships and 57,100 GT. In 1991 it reached its maximum with 56 vessels and 91,851 GT. Nowadays it is made up of 27 vessels with 73,343 GT.

these first campaigns, larger ships began to be built soon such as "Sarasua" with 1477 GT launched in 1967 and based in Huelva, followed by others such as "Costa de Marfil", "Sol de Ipanema" or "Sol de Copacabana", launched between 1971 and 1972, as well as medium-sized vessels commissioned by companies from Bermeo such as "Beti-Alai", "Juan de Akurio" or "Txori"[4].

At the end of the 1970s the boats launched were close on average to a tonnage of 2000 GT, such as "Almadraba Dos" or some belonging to Albacora firm. From the 1990s, ships which were much larger began to be built. The tonnage of a lot of them were higher than 4000 GT such as "Albacora" or "Albacora Uno". Therefore, from 1995 nearly all ships built exceeded 3000 GT. In this way, the average tonnage expressed in GT has not stopped increasing because it has grown from 646 GT between 1966 and 1970 to more than 3000 GT from 1996 onwards (Fig. 2).

2.3. Policy measures related to the freezer tuna fishing fleet

The fleet is developed under the benefits of Law 147/1961, of December 23, on the renewal and protection of the fishing fleet, whose main objective was to satisfy the internal demand for fishing products, having "an efficient and modern fleet which can make abundant catches with minimal costs", introducing a group of financial and tax benefits to the investment, both in modernising the existing fleet segments and favouring new modalities[5]. The incentives fluctuated between 1962 and 1976, which was the year in which the Law was applied, establishing specific programs for the modalities of "new fishing techniques", which included this segment[6]. In both general and specific rules, the aid consisted of a non-refundable premium or subsidy (6% until 1971 and 5.5% later); a loan from public financial entities for a maximum of 75–80% of the investment with the own ship's mortgage guarantee, at a reduced interest rate, and with a maximum repayment term of 20 years[7], although the term would subsequently be reduced of amortisation, being 10 years from 1968 and increasing the interest rate[8]. In 1971 the launch of the III Economic and Social Development Plan mobilised investments to increase the size of the freezer tuna fleet. Thus, in addition to 8800 GRT in operation at the end of 1970 and 6900 GRT that were being built, other 1600 TRB would be added in the period 1972–1975 and 201.6 million pesetas were allocated to this[9]. The incentives were extended until the end of 1976, at which time a severe economic crisis began in Spain, which severely affected shipbuilding. For this reason, only the same general incentives that were maintained for shipbuilding, which consisted of a 5.5% premium or subsidy, were applied to the building of fishing vessels between 1977 and 1984, and the possibility of getting subsidised loans with interest rates which were never lower than the preferential interest rate for export credits were applied between 1979 and 1982[10]. In this way, the total of public aid to the fleet in question in terms of premiums or interest subsidies, remained above 35% in the periods of time 1962–1967 and 1979–1982. It reached around 25% between 1968 and 1971 and around 20% between 1972 and 1976. It limited itself to the 5.5% premium in the periods of time 1977–1978 and 1983–1984[11]. In the years before the entry of Spain into the EEC, aid for the modernisation of the fishing fleet was again established through Royal Decree 2161/1984 and Royal Decree 2339/1985. They combined premiums of 5.5% of the investment and the interest subsidy on loans of 10 years' amortisation and two years' grace, which could reach up to 85% of the investment. Thus, in the period of time 1985–1986 it was between 26% and 32% of the investments, which required to deregister a ship of a tonnage which was higher than the one built at that moment[12].

When Spain acceded to the EEC, the same incentives applied to the rest of the EEC fleet were used. They started with Royal Decree 219/1987, which developed Regulation (EEC) 4028/1986, replaced by Regulation (EEC) 3944/1990, developed by Royal Decree 222/1991, with investment premiums that were set with contributions of between 10% and 25% from the EEC and were combined with national aid between 10% and 30%. The receipt of these grants was incompatible with any other incentive for shipbuilding and required to deregister ships which exceeded the built tonnage. These aids are followed by those established by Regulation (EC) 3699/1993, developed in Spain by Royal Decree 2112/1994 and Royal Decree 798/1995, replaced by Royal Decree 3448/2000 and Royal Decree 1048/2003, which developed Regulation (EC) 2792/1999, modified by Regulation (EC) 2369/2002. In this way, aid for the building of new fishing vessels, both in the form of direct subsidies or combined with interest subsidies, remained above 35–50% between 1987 and 1999 and were between 20−30% between 2000 and 2008. From then on, aid for the building of tuna vessels has been established by the regulations in force in the EU for shipbuilding, specified in Spain in Royal Decrees 1274/2003, 59/2005, 1511/2005, 1619/2007, 237/2013, 701/2013 and 874/2017, which greatly limit this aid - between 3% and 4% until 2017 – and eliminate them later.

A different issue is the tax aid for investment, which, in general terms, can be summarised in the total exemption from Corporation Tax until 1981, passing to the bonus of up to 15% of the quota for investments in fixed assets, which was reduced to 10% from 2004 onwards. In addition, in some periods accelerated depreciation plans have been allowed for the company's fixed assets. But these rules have been common to all sectors of activity since 1981 and fishing, in general, or this segment, in particular, have received a different treatment.

Another type of existing incentives, which affect the entire Spanish fishing fleet, are fuel consumption subsidies. In Spain, fuel prices are among the lowest in the European Union due to the tax amount [53]. In addition to the Value Added Tax (VAT), whose applicable rate is very similar throughout the EU - between 20% and 23% depending on the country - other taxes of a special nature are accumulated in the final fuel

[4] The vessels deregistered were sold very soon to canning companies in Huelva and Lanzarote and were converted to fishing for sardines at the Saharan fishing grounds.

[5] Article 10 c) of the Law stated the building of vessels that implied the introduction of new fishing modalities that were of interest to the Spanish economy. As we have seen, in a situation in which tuna landings had been significantly reduced necessarily included the expansion of the freezer tuna purse seine fleet.

[6] These specific incentives began with Order 7/11/1962 and were maintained until Order 19/5/1965, allocating a total of 1700 million pesetas that were added to the 1265 million mobilised under Decree 18/1/1962 destined to this segment.

[7] See Decree 7/1962, of January 8, which indicates the total number of credits for the development of the Plan for the renewal and increase of the fishing fleet and rules for its concession are given, as well as the Order of January 19, 1962 by which provisional rules are issued for the application of the Law of Renewal and Protection of the Fishing Fleet of December 23, 1961.

[8] In specific aid, the interest rate was higher (5.5%), while from 1968, with the entry of commercial banks, the rates applied were their preferential rates, which grew from 5.8% in 1968 to 8.48% in 1976, between 4 and 6 points below market interest rate. See Argandoña [52] and Sánchez Blanco [49].

[9] These new incentives, developed by successive Ministerial Orders, encouraged the building of vessels which were greater than 750 GRT, for which the maximum amount to be financed was 70% of the investment without premiums and tax incentives, with subsidised loans of 10 years' repayment term and 2 years' grace.

[10] See the Order of October 21, 1975, which extended the conditions of the Order of July 31, 1972, during 1976.

[11] These incentives for the building of fishing vessels developed in the 1960s and early 1970s were comparable to those existing in most of the countries that made up the EEC at that time. See García Revuelta [51].

[12] Given that the segment arises under the protection of Law 147/1961, between 1962 and 1971 the contribution of withdrawals was not established in the specific aid for the building of freezer tuna vessels. From 1972 to 1976, only 20% of withdrawals of the built tonnage was required as long as the new ship exceeds 750 GRT, being 60% for those between 500 and 750 GRT.

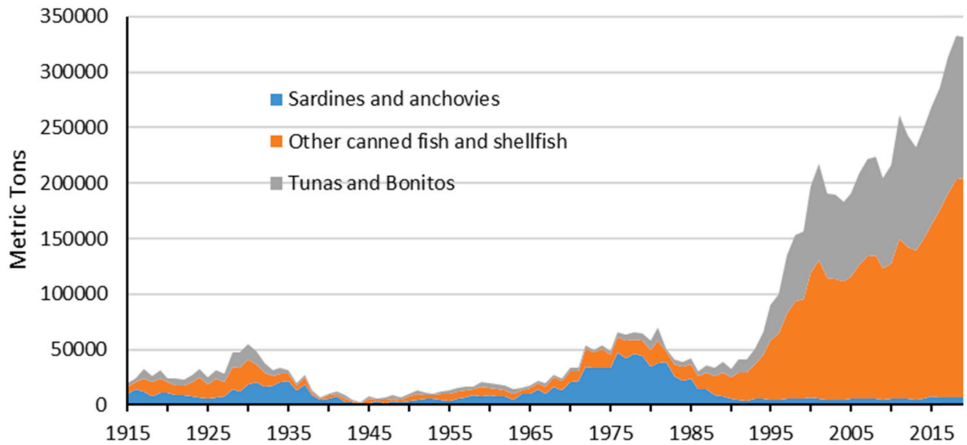

Fig. 3. Evolution of Spanish exports (MT) of fish and shellfish (1915–2019).

prices. In Spain there are two different taxes; the Special Tax on Hydrocarbons and the Tax on retail sales of certain hydrocarbons, which are added to VAT, so that fuel prices are the result of the sum of four components[13]. The evolution of the price per litre consumed for fishing had a decreasing trend until 1978. It went from 0.44 €/l in real terms (base 2010) in 1963–0.16 €/l in 1978. Thereafter there was a quick increase with a cumulative increase of 260% until 1981. Then, it remained at very high levels until 1985 when it began to decline slowly. It took values comparable to those of the early 1970s between 1993 and 1998. The subsequent evolution is characterised by fluctuations in crude oil prices with an upward trend until 2014 - when prices were even higher than those from the period of 1985–1986. Later, it stabilised at somewhat lower prices. Logically, the fuel consumption in the fleet is very high. It remained at 20% of the production value in 2012 when fuel reached the last maximum. Currently it is at just over 16% of the production value. However, as Hospido and Tyedmers, ([26], p. 183) point out, "In burning just under 440 l of fuel per tonne of tuna landed, Spanish purse seiners targeting Skipjack and Yellowfin tuna are relatively energy efficient when compared with many other fisheries for human consumption", although those that operate in the Indian Ocean and in the Atlantic Ocean have somewhat higher consumption per ton of catch, depending on the search movements of the schools [38], but much lower than that of other fishing fleets [2,35]. On the other hand, the ships built in recent years are much more efficient than those of two decades ago [30,46].

2.4. The adaptation of the canning sector

Furthermore, this development was encouraged by the increase in the demand for canned tuna that would become the hegemonic product of the Spanish canning sector in the medium term. The reduction in production from tuna traps and the Cantabrian coastal region had increased the raw material price and, consequently, Spanish canned tuna became an almost luxury product. In 1961 some industrialists obtained authorisation for the import of quotas of frozen tuna without tariff. From that moment onwards, the duty-free imports for the processing industry were generalised. In 1963 1028 MT of tuna were imported, in 1973 these imports already amounted to 7526 MT and in 1983 they were 23,220 MT. All this boosted the canning industry that largely reoriented its activity towards species of tropical tuna and albacore. Therefore, if in 1963 canned tuna represented 18.5% of the production in terms of value, in 1980 it exceeded 40% and in 2010 it represented 60% of the production of the Spanish canning sector.

Moreover, a large part of the Spanish catches is exported both frozen and transformed into preserves, whereas a large number of canned tuna and tuna loins are imported and are subsequently processed and destined to the Spanish market and export.

As a matter of fact, as can be verified in Fig. 3, there are three periods of expansion of canned fish in Spain. The first period is between 1905 and 1921 and is associated with the export of canned sardine from Galicia and Western Andalusia. The second period is associated with canned bluefin tuna exports produced by Andalusian tuna traps and it extends from the late 1910s to the late 1920s. In the third period, i.e. from the early 1960s to the early 1980s, the expansion of canned sardine from the Canary Islands to West African markets occur. Finally, from that decade to the present, a tremendous growth of canned tuna happens. It was 2187 MT, which accounted for only 7% of canned products exported in 1970. Afterwards, it increased to 6864 MT and 27% of canned exports in 1990. Nowadays, it is 122,913 MT which represents 65.7% of the exports of canned fish and shellfish. Overall, Spanish tuna imports were 214,143 MT in live equivalent weight in 2019, while exports were 245,184 MT in live equivalent weight. Furthermore, the foreign trade of canned tuna should be added to it, that is, 154,667 MT in live equivalent weight imported and 94,460 MT in live equivalent weight exported[14].

Thus, the consumption of the Spanish market can be estimated at around 18% of total catches worldwide, whereas the catches of the Spanish fleet represent 6% of this variable. The Spanish consumption per capita almost triples the one of the EU, being 7.55 kg per person and year in 2019. Almost 80% of this consumption is in the form of canned food, whose market has expanded progressively from the late 1970s to the early 1990s because of the aggressive advertising campaigns made by the main brands in the sector. The apparent consumption of canned tuna per capita currently represents almost forty times the world average and four times the EU average. However, at the end of the 1970s, despite the fact that it was relevant, it was only ten times the world average and three times the average of the countries that

[13] Both special taxes have a fixed tax rate for each litre consumed, from which fishing is exempt. In Spain it represents around 85 €/100 litres for Diesel B, which is the one used by fishing vessels, while the general rate for other types of Diesel is set at 331 €/100 litres. In France, the specific taxes applicable to diesel consumption by fishing vessels represent about 108.4 €/100 litres, while in Italy they amount to 185.22 €/100 litres. Therefore, the differences with the general rate are 20% in Spain, 23.2% in France and 30% in Italy, to mention the countries that have or have had tuna freezer purse seine fleets.

[14] It is interesting to note that the conversion factors used for each product and form of presentation provided by EUMOFA [12] may be underestimating these figures because Spanish canned tuna in oil, which is the hegemonic product, usually has a higher proportion of tuna meat than those from other European countries.

Table 1
Augmented Dickey-Fuller test.

Variable	Exogenous variables	No. of lags	t statistic	Variable	Exogenous variables	No. of lags	t statistic
AC	τ	0	-0.97	ΔAC	τ	0	-7.68***
CAC	τ_μ	2	-1.39	ΔCAC	τ_μ	1	-7.21***
CACSK	τ_τ	0	-4.19***	ΔCACSK	τ_μ	1	-8.40***
CACYF	τ	0	-0.22	ΔCACYF	τ	0	-7.57***
CCQ	τ_τ	3	-1.88	ΔCCQ	τ_τ	2	-7.19***
CFA1	τ	0	-0.92	ΔCFA1	τ	1	-6.18***
CT	τ	2	2.06	ΔCT	τ_μ	1	-11.40***
ECQ	τ_τ	0	-1.65	ΔECQ	τ_τ	1	-6.74***
EQV	τ_τ	0	-5.21***	ΔEQV	τ_μ	4	-6.07***
GTC	τ_τ	5	-2.46	ΔGTC	τ	4	-1.19
GTES	τ_τ	0	-2.76	ΔGTES	τ_μ	0	-9.44***
GTEX	τ_τ	3	-3.07	ΔGTEX	τ_μ	1	-4.48***
ICQ	τ_τ	2	-0.24	ΔICQ	τ_τ	1	-7.06***
IQV	τ_τ	0	-2.72	ΔIQV	τ	0	-8.82***
POEST	τ_μ	1	-2.54	ΔPOEST	τ	0	-11.07***
PRGAS	τ	0	-0.39	ΔPRGAS	τ	0	-6.48***
QIADF	τ	0	-1.18	ΔQIADF	τ	0	-8.71***
QIANDF	τ	1	1.93	ΔQIANDF	τ	0	-9.69***
QITA	τ_τ	0	-3.19*	ΔQITA	τ	0	-8.67***
QPCAB	τ_τ	0	-2.47	ΔQPCAB	τ_μ	0	-9.26***
TADRCN	τ	1	-1.27	ΔTADRCN	τ	0	-9.41***
TIM1	τ_τ	0	-1.68	ΔTIM1	τ	0	-5.80***
TIN1	τ_τ	4	-1.32	ΔTIN1	τ	5	-1.71*
TS1	τ	0	-1.48	ΔTS1	τ	3	-5.96***
VMT	τ_τ	1	-5.16***	ΔVMT	τ_μ	3	-6.53***

Note: Critical values are taken from MacKinnon [32].
* Significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level.
Exogenous variables: τ_τ indicates that the auxiliary regression of the Augmented Dickey-Fuller test includes a constant and a trend; τ_μ indicates that it only includes a constant; τ indicates that it does not include any deterministic component.
The Hannan-Quinn information criterion has been used to determine the number of lags of the auxiliary regression. The maximum number of lags is 5.

currently make up the EU.

Logically, the importance of the extractive and processing sectors linked to tuna justifies the need to analyse the interrelations between the main variables and indicators related to these activities. That is precisely the objective of this work, that is, to analyse the interrelations between the extractive sector, the processing sector and the market in Spain, using yearly time series for the period of time 1963–2019, obtained from different statistical sources, to which we will apply conventional econometric techniques of causality analysis [41]. The results of this analysis will allow us to prepare a conceptual map of the existing relationships that helps to understand the phenomena linked to the expansion of the fleet dedicated to this fishing modality and the Spanish canned tuna market.

3. Statistical sources used

The time series used correspond to the following aspects: (a) evolution of the fishing fleet of freezer tuna vessels (i.e., vessels with Spanish flag, vessels which have been exported to joint ventures and foreign vessels under the control of Spanish companies); (b) evolution of tuna catches of the considered fleet and other segments; (c) evolution of canned production and the structure of the Spanish canning sector; d) evolution of the foreign trade of fresh, chilled and frozen tuna, as well as foreign trade of canned and processed tuna.

Additionally, from these series we have obtained information on total and per capita apparent consumption, as well as other variables related to the size of the market, the structure of the extractive sector, the organisation of the canning sector and other related aspects. Due to the interest that it may have to validate the results of this work, we will comment on the sources used below, the process for its preparation and, where appropriate, the hypotheses that we have had to establish in order to have relatively homogeneous and comparable time series.

3.1. *Fishing fleet*

A yearly database of all vessels dedicated to this fishing modality has been prepared for the period of time 1963–2019. This information includes technical characteristics, shipowner and business group, association, base port, fishing ground, identification codes and name changes. In total this has meant a set of 2087 records for the Spanish flag fleet, 795 for the fleet exported to joint ventures, and other 610 records for the foreign fleet controlled by Spanish companies. In order to prepare this database, we have used different printed statistical sources: "La Flota Pesquera Española" (i.e., "The Spanish Fishing Fleet"), from 1965 to 1972, which contains aggregated tables by tonnage, age of vessels and maritime district of the base port, as well as a detailed list of vessels of the fleet; "Lista Oficial de Buques" (i.e., "Official Ship List"), from 1963 to 2018, with lists of vessels, with technical characteristics, shipyard, identification codes and shipowner; tables for the segment of the Freezer Purse Seine Fleet contained in the publication "Anuario de Pesca Marítima" (i.e., "Yearbook of Maritime Fishing") between 1973 and 1986, which also presented them aggregated by tonnage, age and maritime district of the base port. In the previous sources the tonnage is expressed in GRT so that for those vessels that do not appear in other sources because of having disappeared, the tonnage expressed in GT has been estimated using regressions.

In addition, different available databases have been used such as the Working Fishing Fleet Census, the EU Ship database, the databases of the different management organisations, as well as different private websites related to fleets and ships, including those of shipowners and associations of the sector. Using all this information, series have been obtained not only about the number of vessels, tonnage in GT or engine power, but also about some indicators on the degree of concentration in the sector. The database has been prepared with the existing fleet on the 31st of December every year. Therefore, to avoid possible problems of time allocation, we have also computed the average of these series to assign the figures in the middle of each year.

3.2. Catches and landings

Fleet catches have been obtained from the databases of the main management organisations of the fishing grounds where the fleet operates (ICCAT, IOTC, IATCC, WCPFC and WCPFO). We have sometimes had to use printed reports published by these organisations. Not only have the catches of the freezer purse seine fleet been considered in a different way, but we have also taken into account those of other segments such as traditional tuna traps, longliners, live bait fleet and small-sized purse seiners operating in the Mediterranean Sea. Series in live equivalent weight have been obtained for each species, fishing ground and fleet segment. The series of catches and fish landings published by the Spanish authorities - "Estadísticas de Pesca" (i.e., "Fishery Statistics"), between 1963 and 1972; "Anuario de Pesca Marítima" (i.e., "Yearbook of Maritime Fishing", 1973–1986; dispersed data from INE (i.e., Spanish National Statistics Institute)) and Fishery Statistics published in the website of the Spanish Ministry of Agriculture have not been considered[15] due to their discontinuity, methodological changes and excessive aggregation, though they have been used to verify the series produced by the management organisations and FAO.

3.3. Canned production

The series related to canned production have been obtained from official sources. For the period of time 1963–1978, the publication "Estadísticas de la Industria Derivada de la Pesca" (i.e., "Statistics of the Industry coming from Fishing") of the INE has been used. For the period of time 1979–1992 the series of the "Industrial Survey", which is also conducted by INE, have been obtained, while from 1993 to present the information is obtained from the "Industrial Survey of Products", which is also conducted by INE. Due to the aggregation of this last source, canned tuna and bonito can be considered together in the series. Other series that are usually used, those provided by the National Association of Canned Fish Manufacturers (ANFACO), have been dismissed because they started at a later time, in 1986, and they did not include information about the methodology or the sample used. Likewise, information about hours worked in the sector, number of companies and number of employees, has been obtained from these publications. Using the aforementioned information, different indicators have been prepared.

3.4. Foreign trade

To obtain the series of foreign trade for fresh, chilled or frozen fish, as well as canned food and other processed products, we have used the annual publications "Estadística del Comercio Exterior de España" (i.e., "Foreign Trade Statistics of Spain") between 1963 and 1967 and, for the period of time 1968–1987, we have used the series "Estadística del Comercio Exterior de España. Comercio por producto y países en Nomenclatura de Bruselas" (i.e., "Statistics on Foreign Trade of Spain. Trade by product and country in Brussels' Nomenclature"). For the rest of the series we have used the databases provided by the Spanish Tax Agency (1988–2019) and its summary available in the database Data-Comex provided by the Spanish Ministry of Industry, Trade and Tourism.

All figures in weight for different formats and species have been expressed in live equivalent weight using the conversion factors de EUMOFA [12]. In addition, in the non-transformed tuna import series, we have deleted the records whose country of origin was "Distant Water Fishing", which were incorporated between 1988 and 1994, because these quantities actually correspond to fish caught by the Spanish fleet and landed in non-national ports to be sent in freighters to Spain. All monetary series have been expressed in constant euros using the CPI (2016 = 100) as a deflator. Overall, 57 series of the different physical and monetary variables have been used, although we only mention in this paper those in which significant relationships have been found.

3.5. Tariff policy

From the entry of Spain into the Organisation for European Economic Co-operation in 1958, the liberalisation of imports of fishery products began with those of cod (Resolution 30/5/1960), extending to the rest of fishery products corresponding to the tariff headings included in Group 03 in the following year[16]. But, in turn, despite the establishment of the corresponding tariffs, additional duties are introduced (Decree 28/03/1963) "for the regulation of the price of food products". Therefore, an extra-tariff protection against massive imports was established for imports of these products [50]. These duties are extended to the field of fishery products by Decree 631/1964 and, thereafter, tax rates in monetary units per imported ton were established through resolutions of monthly or biweekly frequency[17]. This state of affairs would continue until 1972, when the so-called variable compensatory duties are also introduced by means of Decree 3221/1972 and the previous regulatory duties are used for products with defined prices in international markets. The procedure for its establishment was based on the analysis of the fishing markets through a system of reference prices. These duties began to be applied in 1975, after the publication of the Import Regulations for Fish, Molluscs and Crustaceans, with monthly, fortnightly and even weekly updates, and their application was extended until Spain entered into the EEC in 1986[18]. However, in some periods, tariff-free quotas of all kinds are introduced, as was done in 1968 and 1969 for trap bluefin tuna, to support the Tuna Trap National Consortium, or as established in 1977 for catches from exported vessels to Joint Fishing Companies, which were set up under Royal Decree 2517/1976, which were extended until 1992 under article 168 of the Treaty of Accession of Spain to the EEC[19]. After a transitional period between 1987 and 1992 in which the tariff duties were progressively

[15] Additionally, in this last source, there are errors when computing the catches of this fleet between 2012 and 2015, undervaluing them significantly.

[16] From that year, customs duties for fresh tuna were zero, whereas frozen tuna were taxed at 20% of the value of imports, remaining like that until 1975, when duties were reduced to 6% for tuna destined for processing.

[17] For frozen fish in the tariff heading EX03.01. C, which included tuna, 4000 pesetas/MT are initially established in 1965. In the same year they were increased to 12,000 pesetas/MT until 1968, when they were slightly reduced, and 10,050 pesetas/MT were applied until 1972. Finally, they were at the token amount of 10 pesetas/MT on 21/4/1972.

[18] The countervailing duties applicable to imports of tuna were established in March 1975 at 5000 pesetas/MT, but almost immediately they were increased to 20,000 pesetas/MT. They remained at this level until 1980, when they increased significantly and reached around 50,000 pesetas/MT depending on the product. However, the application of duties was sometimes suspended to allow the massive entry of imports in periods of shortage of catches.

[19] Nonetheless, its quantitative importance was reduced because only two vessels of the Conservas Garavilla, S.A. group took advantage of this regulation, being exported to Ecuador in 1981. The established quotas reached a maximum of 1650 MT in 1986, gradually being reduced until they reached a quota of 289 MT in 1992.

adjusted, from 1993 the tariff regime is based on Regulation (EEC) 2658/1987 and its successive modifications and adaptations[20]. Series have been prepared about the evolution of customs duties from 1963 to the present. To this end, due to the fact that the regulatory and compensatory duties were expressed in pesetas per MT, the cost per 100 MT of these duties has been estimated for each product and species. In addition, the rate of duty established on the value of 100 MT at the average price for the year considered has been applied. Likewise, series on quotas with reduced or zero duties have been used for both Group 03 - fish - and Group 16 - canned food. Furthermore, both the quantities corresponding to tuna destined for processing and those that are not destined for processing have been differentiated in the series of imports by weight.

3.6. Subsidies for the construction of new vessels

Series have been prepared from 1963 to the present about different variables related to the incentive policies for ship building that was commented on in Section 3. First of all, given that there are basically two types of incentives - premiums and interest subsidies - we have obtained the market interest rate from different sources indicated in Section 3 and from the statistics of the Bank of Spain. The net interest rate has been obtained by applying different regulations. Based on this one and with the applicable credit conditions according to the different calls (term, grace period, maximum amount to be financed), loan amortisation tables have been prepared. The amount subsidised has been obtained as the difference between the interest accrued by the market interest rates and the applicable net interest rates, discounted to the year of the contract using the net interest rate. This way, the total subsidy, expressed as a percentage of the value of the vessel, includes the applicable premium plus the subsidised interest. We have used both the net and market interest series, as well as the total financial cost - accrued interest – on the investment value and the total subsidy (premium + discounted interest savings) expressed as a percentage.

3.7. Fuel price data

A series of the applicable fuel prices for the fishing sector has been obtained for the period of 1963–2019. To do it, data from the Wholesale Price index were used until 1972. Then, the information provided in the successive regulations was used until 1986, when prices were established by regulation. Later, the average price statistics prepared by the Spanish National Commission of Markets and Competition (CNMC) were employed. We applied to those series the tax rates established on the consumption of hydrocarbons which were mentioned in Section 3. The evolution of the tax rates has been obtained from the Statistics of the Special Hydrocarbon Tax prepared by the Tax Agency (AEAT).

[20] To sum up, the tariff duties derived from the Regulation consist of establishing zero duties on imports of fresh or frozen tuna destined for industrial processing and establishing duties of 22% for the rest of tuna. This tariff policy is completed with the introduction of tariff quotas for certain countries and products. In addition, regarding canned food, the applicable rate for tuna fish is 24% and it is 25% for bonito. It is worth highlighting the introduction of quotas for "fillets called tuna loins" with quotas with a reduced tariff established through Regulation (EC) 1734/1996. Initially they were 1000 MT at 12% and increased to 1200 MT with a tariff rate of 6% the following year. These quotas have been growing up to 15,000 MT by Regulation (EU) 1006/2011. The following year, the tariff duties for the quota were eliminated. It grew to 22,000 MT by Regulation (EU) 2012/927 and to 30,000 MT by Regulation (EU) 2018/1602.

4. Methodology

Granger's concept of causality was introduced in one of his works [19]. Causality in Granger's sense is defined as follows: "We say that Y_t is causing X_t if we are better able to predict X_t using all available information than if the information apart from Y_t had been used" [19]. In other words, if better predictions of a time series Y are obtained taking into account all the past information that could have an influence on this variable than considering the same information but not including the time series X, then it can be said that X Granger causes Y. Therefore, X Granger causes Y if the prediction made for the variable Y is improved when considering the past information of the variable X.

Once the concept of Granger causality has been defined, the causality relationship between variables have been studied using the approach suggested by Toda & Yamamoto [41]. This procedure makes it possible to test causality in Granger's sense by avoiding the undesirable consequences associated with the power and size properties of unit root and cointegration tests [48]. Therefore, it is possible that incorrect statistical inferences could be made about the causality relationship between variables simply because of the sensitivity of unit root or cointegration tests due to the aforementioned power and size properties. According to Hacker and Hatemi ([21], p. 1489), the main advantages of Toda–Yamamoto modified Wald (MWALD) test are "its simple application, its absence of pre-testing distortions, and its basis on a standard asymptotical distribution irrespective of the number of unit roots and the cointegrating properties of the data." In this way, to apply the procedure suggested by Toda & Yamamoto [41], the steps are as follows:

1. Determine the order of integration of the time series. To do it, in this paper the Augmented Dickey-Fuller (ADF) unit root test has been used [9]. This test has been performed on the time series in levels and in first differences. Likewise, the Hannan-Quinn information criterion has been used to select the number of lags to be included in the auxiliary regression of the test. Therefore, the inclusion of these lags allows us to guarantee that the residuals of the auxiliary regressions are a white noise process.
2. Obtain the maximum order of integration (d_{max}) of the set of variables considered.
3. Estimate a VAR model with the variables in levels.
4. Determine the optimal number of lags of the VAR model (k). To do it, the Akaike Information Criterion has been used.
5. Verify that the VAR model is correctly specified. To do this, the lack of serial correlation in the residuals has been checked using a multivariate LM test [27].
6. Estimate a VAR model of order k + d_{max}. Thus, the usual statistics of Granger causality test have the asymptotic standard distribution [47].
7. Test for Granger non-causality. For a VAR model with two variables:

$$X_{1t} = \alpha_0 + \sum_{i=1}^{k} \alpha_{1i} X_{1,t-i} + \sum_{j=k+1}^{d_{max}} \alpha_{2j} X_{1,t-j} + \sum_{i=1}^{k} \varphi_{1i} X_{2,t-i} + \sum_{j=k+1}^{d_{max}} \varphi_{2j} X_{2,t-j} + \varepsilon_{1t}$$
$$X_{2t} = \beta_0 + \sum_{i=1}^{k} \beta_{1i} X_{2,t-i} + \sum_{j=k+1}^{d_{max}} \beta_{2j} X_{2,t-j} + \sum_{i=1}^{k} \phi_{1i} X_{1,t-i} + \sum_{j=k+1}^{d_{max}} \phi_{2j} X_{1,t-j} + \varepsilon_{2t} \quad (1)$$

To test that X_2 does not Granger cause X_1, the restriction $\varphi_{1i} = 0\ \forall i$ is tested. Likewise, to test that X_1 does not Granger cause X_2, the restriction $\phi_{1i} = 0\ \forall i$ is tested. To perform these tests, a modified Wald test based on Ordinary Least Squares (OLS) estimates of the augmented model expressed in Eq. (1) is used [10].

Finally, a leveraged bootstrap distribution has been used to reduce the size distortions of the aforementioned MWALD test [21–23] because this test performs poorly in small sample sizes when using its asymptotical distribution, that is, the chi-square.

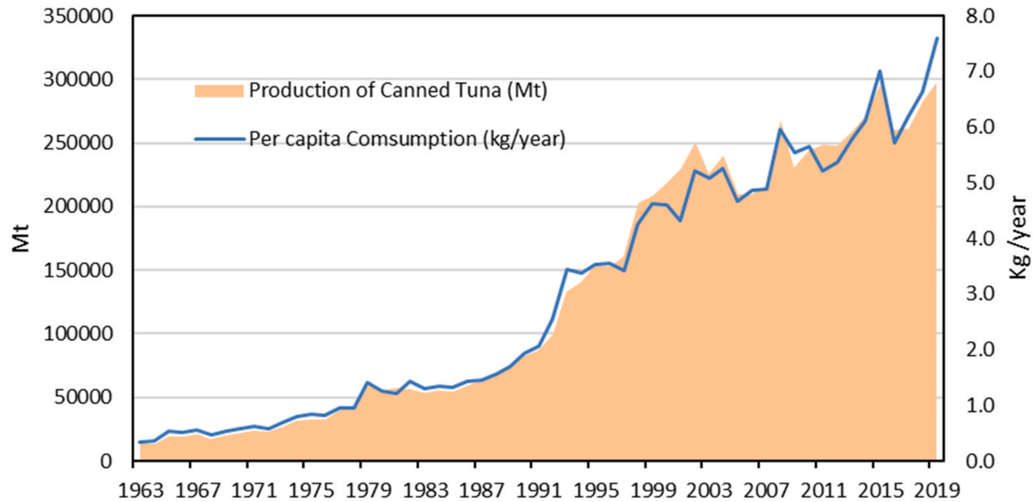

Fig. 4. Evolution of canned tuna production and per capita consumption in Spain (1963–2019).

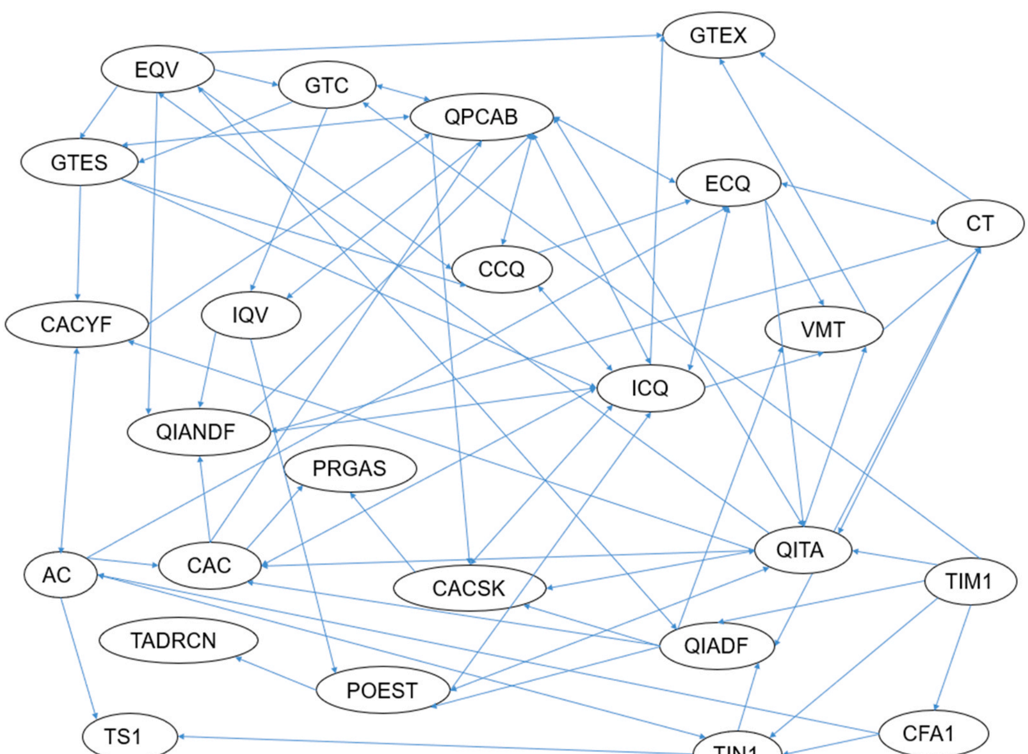

Fig. 5. Main causality relationships in the Granger sense found by Toda & Yamamoto method with the complete sample (1963–2019).

5. Empirical results

As mentioned above, to apply the Toda & Yamamoto [41] procedure, first of all, the order of integration of the time series has been analysed using the Augmented Dickey-Fuller (ADF) test [9]. This test has been performed on the time series in levels and in first differences. As shown in Table 1 [21], most series are I(1), that is, they have one unit root. These time series are: AC (canned tuna tariff), CAC (total catches of tropical tuna per purse seiner (MT) (Atlantic Ocean, Indian Ocean, Pacific Ocean)), CACYF (yellowfin tuna catches of tropical tuna per freezer purse seiner (MT)), CCQ (apparent consumption of canned tuna (MT)), CFA1 (discounted financial cost (expressed as a percentage on investment)), CT (total tuna consumption (MT)), ECQ (exports of canned tuna in terms of weight (MT)), GTES (average capacity of the Spanish fleet (GT)), GTEX (total fleet capacity (exported under control) (GT)), ICQ (imports of canned tuna in terms of weight (MT)), IQV (imports of tuna in terms of weight (live equivalent weight) (MT)), POEST (personnel employed/company (fish processing sector)), PRGAS (real price of fuel for fishing (Diesel B) (constant € of 2010)), QIADF (total imports of tuna which are destined for processing in terms of nominal weight (MT)), QIANDF (total imports of tuna which are not destined for processing in terms of nominal weight (MT)), QPCAB (canned tuna production in

[21] In Table 1 only those variables that are included in causal relationships that appear in the graphs (Fig. 5 and Fig. 6) have been shown.

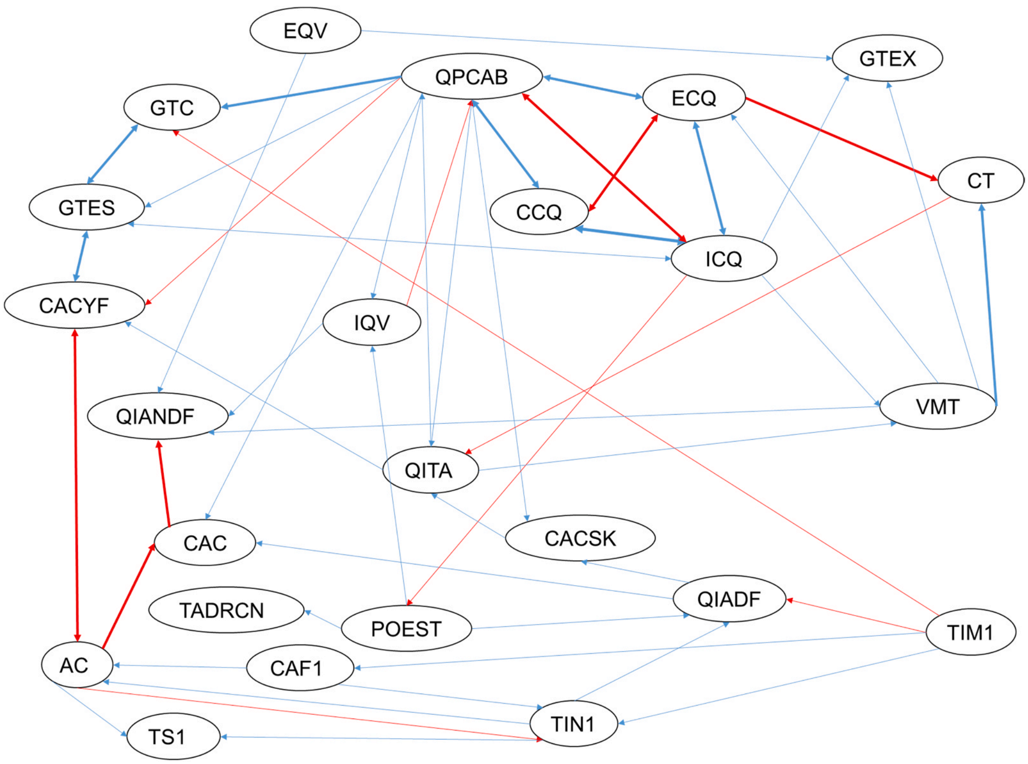

Fig. 6. Final configuration of the network of interrelations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

terms of weight (MT)), TADRCN (total duties on tuna imports (the sum of tariff, regulatory duties and countervailing duties)), TIM1 (market interest rate), TIN1 (net interest rate of subsidies) and TS1 (total subsidies (expressed as a percentage on investment)). On the other hand, GTC (total fleet capacity (foreign under control) (GT)) is I(2), that is, it has two unit roots. Finally, CACSK (skipjack tuna catches of tropical tuna per freezer purse seiner (MT)), EQV (exports of tuna in terms of weight (live equivalent weight) (MT)), QITA (total imports of tuna in terms of nominal weight (MT)) and VMT (average sales per fish processing company (thousand constant € of 2016/company)) are I(0) and are therefore stationary.

After obtaining the order of integration of the series, the VAR models were estimated with the variables in levels. To do it, an intercept has been included in the models as a deterministic component. To compute the number of lags to include in the VAR models, in general the Akaike information criterion [31] has been used. However, the number of lags to include in the VAR models has been changed until a valid model has been obtained in those cases where the VAR model chosen has shown serial autocorrelation problems.

Table A.1 [22] shows for each VAR model considered the number of lags (k) included, the LM multivariate autocorrelation tests up to order 1 and order 5 [27] and the maximum order of integration of its variables (d_{max}). The results indicate that the models are correctly specified at a significance level of 5%.

After checking the adequacy of the VAR models, the Toda-Yamamoto causality tests have been performed. Table A.2 shows the significant causal relationships that appear on the graph in Fig. 5. Additionally, it includes the bootstrap critical values [21–23]. With these results, we can make some comments and interpretations about the economic implications of the causal relationships found.

The main results of the causal relationships found are shown in a directed graph (Fig. 5). The nodes which have the highest outdegree are canned tuna imports (ICQ) and canned tuna production (QPCAB). Canned tuna imports (ICQ) have an influence on apparent consumption of canned tuna (CCQ), average sales per processing company (VMT), tropical tuna catches (CAC, CACSK), exported fleet capacity (GTEX) and canned tuna production (QPCAB). Canned tuna production (QPCAB) has an influence on canned tuna exports (ECQ), apparent consumption of canned tuna (CCQ), canned tuna imports (ICQ), Spanish fleet capacity (GTES) and foreign fleet capacity controlled by Spanish companies (GTC).

Fig. 5 shows the main causal relationships detected by the Toda & Yamamoto procedure. It is apparent the central role played by canned tuna in the functioning of the system, around three nodes: consumption of canned tuna in the Spanish market, canned tuna production and canned tuna imports, which include imported tuna loins for further processing, which currently represent 28,600 MT and nearly all imported tuna loins. Consumption of canned tuna in the Spanish market represents 15.7% of world consumption and 44.4% of consumption in the European Union. However, this analysis has its limitations because, first of all, it does not allow us to determine the sign of the directions of causality and, furthermore, it does not allow us to quantify in a bivariate relationship to what extent it is affected by the remaining variables of the system. A simple tool that can help us to solve these questions is to make use of bivariate correlations and partial correlations. The first ones, which we have estimated using Pearson's correlation coefficient, measure the degree of linear association and its sign between two nodes of the system, without considering the interrelationships with the remaining variables. In contrast, partial correlations allow the sign and the magnitude of the relationship between two nodes eliminating the effect of the variables that influence the two considered to be quantified. There are quite a few studies that combine the results of a causality analysis with correlation analysis to refine the multivariate

[22] In Table A.1 only those VAR models whose variables are included in causal relationships that appear in the graphs (Fig. 5 and Fig. 6) have been shown.

interrelationship graph [1,6,28,29][23]. In our case we have split the set of variables (nodes) considered in Fig. 5; Pearson's bivariate linear correlation coefficients and their significance levels improved by bootstrapping have been obtained. In addition, the partial correlation coefficients have been obtained for each relationship, eliminating in each case the influence of the remaining variables entering the response node. In this case, the estimates have also been improved by bootstrapping. The results are shown in Table A.3.Once these results have been obtained, we have applied a simple algorithm which selects those entry or exit routes which, first of all, have a high significance in the causality tests, in which the bivariate correlations are high in absolute value and in which, additionally, the partial correlation between both nodes also takes a high value with a maximum significance level of 10%, in order to incorporate the maximum number of relationships.

The final graph resulting from this analysis has been displayed in Fig. 6. This graph includes only those nodes and relationships in which there are significant causal relationships and, additionally, the bivariate and partial correlations are significant, at least, at 10%. In this figure we have marked the inverse relationships between variables in red line - negative partial correlations - and direct ones in blue line - positive partial correlations. In addition, the thickness of the line indicates partial correlations which are higher than 0.5 in absolute value.

The most important nodes of the system shown in Fig. 6 correspond to the subsystem made up of the canning sector. Canned tuna production (QPCAB) with an outdegree of 9 and an indegree of 6; canned tuna imports (ICQ) which has an outdegree of 7 and an indegree of 4; the apparent consumption of canned tuna in Spain (CCQ), with an outdegree of 3 and an indegree of 3; and exports of canned tuna (ECQ) with an outdegree of 4 and an indegree of 4; make up this central core of the graph, concentrating 36.5% of the outdegrees and 27% of the indegrees. The causal relationships between these four variables are all bidirectional, except for the one between apparent consumption and exports, which is only significant from CCQ to ECQ, inversely - the higher the consumption is, the lower the exports are. They are also causal relationships with very high significance which are less than 1%. Consumption (CCQ) positively influences both canned tuna production (QPCAB) and canned tuna imports (ICQ) because these variables also include tuna loins, which 99% of them are sent to the canning industry for its processing. But production also influences consumption - it is a bidirectional edge. This is a somewhat unexpected result, which we will explain later, and production is inversely related in a bidirectional way to canned tuna imports. Both variables and domestic consumption determine canned tuna exports directly.

6. Discussion

In this work we have used the Toda-Yamamoto procedure to find causality relationships in the Granger sense between time series related to the freezer tuna fleet, the Spanish canning sector and the frozen tuna and canned tuna markets, analysing a relevant number of relationships between the variables considered. Obviously, there may be many other causal relationships between the variables considered. Considering the 81 series used, we have tested the possible existence of causal relationships in the Granger sense using mainly bivariate tests and, to a much lesser extent, multivariate tests, for those series in which we considered their consideration appropriate. We have found 26 causal relationships at the 1% significance level, other 40 causal relationships at the 5% significance level and, finally, other 24 causal relationships at the 10% significance level.

The important role of domestic consumption of canned tuna remains constant in the Spanish market over time. It grew very rapidly at the end of the 1970s (Fig. 4) due to the introduction of the first circular cans instead of the traditional oval ones, due to the popularisation of canned yellowfin tuna and, above all, because of the aggressive advertising campaigns that were launched by some of the canning companies from the end of the 1970s[24]. As a matter of fact, between 1970 and 1980, the per capita consumption of canned tuna doubled, going from 0.58 kg/inhabitant to 1.25 kg/inhabitant, and it multiplied by four in the following decade. In 1970 19,639 MT were consumed, then in 2000 184,416 MT were consumed and in 2015 consumption exceeded 300,000 MT. This increase in consumption was caused by the change in packaging, can packs, advertising campaigns and, above all, the drop in prices in real terms. The average real price per kg of canned tuna fell between 1965 and 1985 by 21%, and until 1995 by more than 40%. Furthermore, the behaviour of the Spanish canned tuna market is clearly unique because it behaves like a luxury good with an expenditure elasticity which is much higher than one. As a result, demand grows more than proportionally when income increases. It contrasts with the rest of canned fish or shellfish [17, p. 132][25].

Canned tuna exports and imports can be considered the cause of the average size of companies in the canning sector - measured by their sales in real terms (VMT). In other words, the growth of the sector has driven its concentration, that is, a sector where few companies (Calvo, Garavilla) have an oligopolistic situation [20]. These large canneries participate in shipowning companies or have their own fleets. But, in addition, shipowning companies have been progressively associating with companies involved in both the processing of tuna loins and the preservation and freezing of tuna [44].

Moreover, the fleet with the Spanish flag measured by its average capacity (GTES) is the cause of the catches that, in turn, have a decisive influence on the production of canned tuna. Nonetheless, in addition, the expansion of canned tuna production has also driven the growth of a fleet made up of vessels that have never had a Spanish flag before, but they are under control of Spanish companies. This process has also become more important in recent years because many ships commissioned by the main business groups also built in Spanish shipyards, are for companies under total or partial control of Spanish associates. The first foreign ship under control of Spanish companies was "Olivia" with

[23] This procedure has certain limitations because the causal relationship can operate with lags, while the correlations measure contemporary relationships. However, as we shall see, in the cases in which doubts have arisen - strong causal relationships and low bivariate and partial correlations - we have chosen to include this relationship if in the VAR model estimated to perform the causality test, the coefficients with lags are very significant. This only occurs in two cases: the relationship from ICQ to VMT and the bidirectional relationship between ECQ and CT.

[24] For example, "Conservas Calvo" launched the spot "Atún claro, Calvo" (1979) or Garavilla started the campaign "¡Qué bien, qué bien, hoy comemos con Isabel!" (1981). They were well prepared, they had clear messages and they were the first canning company advertisements which were watched on television. The absence of specific public campaigns for canned tuna stands out as opposed to these private campaigns. Although FROM campaigns were carried out for all fishery products from 1997 to 2007, they were general campaigns on canned products, frozen products, fresh products, etc. Campaigns were carried out to promote the consumption of tuna in some years (2002–2007). These campaigns were the responsibility of the Fund for the Regulation and Organization of the Market of Fishery and Marine Culture Products (FROM).

[25] In addition, if we compare with the main EU canned tuna producing countries, it can be verified that in Spain, from 1976 to 2019, the average price of canned tuna in real terms has decreased 74.5% while apparent consumption per capita has grown 700%. Italy, whose production in 1976 was higher than Spain (38,000 MT compared to 32,980 MT), consumption per capita has increased 367% and the average price of canned tuna in real terms has diminished 54.3%. Finally, France, with a production in 1976 of 16,100 MT of canned tuna, has experienced a much smaller increase in consumption per capita - 190% - with a reduction in price in real terms of 29.7%. If we analyse the events since 1996, both in Italy and in France the real price has increased (15.3% and 11.9%, respectively) while in Spain it decreased 7%. In other words, there seems to be a direct relationship between consumption and production, and an inverse relationship between prices and consumption.

1376 GT in 1974. In 1990 there were already 9 ships operated by companies owned by Spanish business groups with 17,064 GT as a whole. In 2000 this figure had risen to 19 with a total tonnage of 44,488 GT and currently there are 21 vessels with 52,857 GT. Although the first ships with a foreign flag under the control of Spanish shipowners were built in Spanish shipyards, only 27% of the tonnage of that subsegment came from this origin in 1998. The rest of ships were acquired in other countries, both from the EU (France, Italy) and third countries. However, from 2014 a total of 8426 GT have been built in Spanish shipyards. It represents 15% of the total in this subsegment and they are built at a time when incentives for shipbuilding are minimal.

The export of ships to joint fishing companies and to joint ventures later was the consequence of the specific policies of access to fishing resources of coastal countries. In the case of the freezer tuna sector, the first exported vessels that maintain their ties with Spanish companies are two ships which belong to “Conservas Garavilla” business group, where from 1976 there was a processing plant of the subsidiary “Conservas Isabel Ecuatoriana, S.A.”, located in the town Manta. These ships, "Isabel Dos" and "Isabel Tres" were joined by other ships later, such as "El Almirante" (2001) or "Isabel Cinco" (1998). A similar process was experienced by “Grupo Calvo”. In 2003 this business group opened a processing plant for tuna loins in El Salvador, and most of its freezer fleet has been allocated there after having registered them in other countries (Cape Verde, Seychelles or Ecuador) to guarantee access to resources. Other companies such as “Grupo Albacora” have also used the set-up of joint ventures and the registration of ships in third countries to guarantee access to resources. This company started with the export of “Albacora Diez” and “Albacora Nueve” in 1992 to Panama and it currently has five large freezers with different flags at its convenience. In short, the activity of this fleet (GTEX) is influenced by imports of tuna (QIANDF), being the cause of the consumption of tuna (CT). This last variable can in turn be considered as an effect of canned tuna exports (EQV), with a negative sign; that is, the higher canned tuna exports are, the lower the domestic consumption of tuna is. Furthermore, CT is also an effect of the average sales per fish processing company. In other words, as the average sales per fish processing company (VMT) have increased, it seems that their ability to influence demand has also grown. The expansion of the freezer tuna fleet occurred as a natural evolution of the old live bait fleet from Bermeo and the sharp decrease in catches of tuna traps. The huge catches of skipjack and yellowfin tuna allowed the reorientation of the canning sector in Northern Spain. At present, almost 60% of Spanish canning production corresponds to tuna. The development strategy of the canning industry and the expansion of the tuna fleet is mainly the consumption in the Spanish market, which, although it was always high, it has experienced a notable increase since the late 1970s due to successful marketing campaigns launched by the main canning firms.

The variables related to the incentive policies for the building of new vessels, such as the Discounted Financial Cost (CFA1), the net interest rate of subsidies applicable to the building of fishing vessels (TIN1) or the total subsidies for vessel building (TS1), showed significant causal relationships with the variables that show the evolution of the Spanish, exported or controlled tuna fleet. A yearly series was even built from 1963 to 2019 about the evolution of the order book of ships in the Spanish shipyards because the date of building or the date in which the ship enters service had an extensive delay in some periods due to the accumulation of orders in the shipyards (1972–1977) or the crisis in the shipbuilding sector (1979–1984). However, these relationships were not significant either. Only the average market interest rate (TIM1), which does not depend on incentive policies, shows a negative causal relationship on the foreign fleet under control (GTC). It can be explained by the increase in the building and acquisitions of ships in periods with low interest rates.

The protectionist tariff policy, that we have intended to consider using variables AC and TADRCN or the series related to the evolution of tariff-free or reduced duty quotas, did not produce any significant causal relationships either, or, as occurs with variable AC, it shows a negative influence on catches of tropical tunas, both on the aggregates (CAC) and yellowfin tuna (CACYF).

The consideration of the subsidised price of fuel in real terms (PGASR) did not provide any significant results either. On the other hand, some inconsistent relationships were obtained. Contrary to what might be expected, catches seem to determine the level of fuel prices. However, these relationships were not significant when the effect of other variables is eliminated using partial correlations.

All these results (i.e. the significant causality relationships confirmed through the correlation analysis (Fig. 6) and the relationships that have not been significant in any of the analyses carried out) allow us to infer that the core of the analysed system focuses on the interaction between the strong consumption per capita of tuna and canned tuna and the existence of a powerful processing industry.

But, in addition, it must be considered that the incentives that this fleet segment has obtained since 1963 have not been different from those of other Spanish fleet segments that developed under Law 147/1961, such as the trawl freezer fleet dedicated to cephalopods, the one dedicated to hake in Southern Atlantic waters or the shellfish freezer fleet dedicated to crustaceans. All of them barely represent 10% of the size they had in 1986, despite the fact that they obtained similar incentives. Not only has the market for tuna and its preparations been growing, but we must also consider that the freezer purse seine fleet has not been so affected by the extension of territorial waters and the limitations imposed since 1978 by most of the coastal states. This is because their licenses are subject to international organisations and a large part of their catches are obtained outside the EEZ, both in the Atlantic Ocean, the Indian Ocean or the Pacific Ocean [44,45].

To sum up, according to the results of the tests, we can state that the most relevant subsystem to explain the dynamics of the sector is formed by the canning industry with its production, foreign trade and domestic consumption. This high demand explains the expansion of the fleets, that is, the one with the Spanish flag, the one which is made up of vessels exported to joint ventures and subsidiaries in third countries, and a growing segment of foreign vessels whose shipowning companies are totally or partially controlled by Spanish firms.

Although the results obtained are important to understand the evolution of the sector, they have their limitations because the significance of these results lies in the quality of the time series used. We should be critical on this point; the quality of Spanish fisheries statistics is debatable and their reliability gets worse as we move away from the present moment. Let us give some examples. During the 1960s and until well into the 1970s, Spanish statistics on catches of frozen tuna fishing barely distinguished between species and, furthermore, when transshipments occurred, they were not even disaggregated. Therefore, it was difficult that data sent to international organisations could be consistent. The statistics on canning production also suffer from too much product aggregation, which has led us to have to consider all canned tuna in a single time series, including those of Northern bonito or albacore tuna. But, in addition, there is no distinction between presentation formats or varieties. Therefore, applying conversion rates is a very difficult task in order to compute physical quantities in terms of live equivalent weight. The fishing fleet time series, that we have reconstructed for this work, can be quite reliable and coincide to a greater or lesser extent with those resulting from other existing works [42]. Nevertheless, in some cases we have not been able to verify whether an existing vessel was active or not in a specific year, despite the fact that it was registered, which may be overestimating the existing fishing capacity to some extent. Regarding the structure of the business sector of shipbuilding companies and canning companies, it is also a difficult task. In the first case, it has been reconstructed through fleet listings and, on occasions, through business register data. In the second case, it has been obtained from the statistics on the canning sector, which implies that sales and employees correspond to the total of the sector. Consequently, if in the last twenty years they could be proxy variables to represent the canned tuna sector given its importance, in the first decades of the time series we would be considering companies dedicated to other canned food to a large extent. Finally, a crucial problem is the foreign trade statistics for fresh, chilled or frozen tunas because until 1976 they did not start to be disaggregated by species and presentation format in the tariff headings. For this reason, we had to add all the tuna to be able to have more or less homogeneous series from 1963 onwards. In the statistics of foreign trade of canned tuna something similar occurs because there is too much aggregation until 1986.

Despite this, the results obtained are sufficiently robust and we think that they have allowed us to glimpse the existing interrelationships between the sectors considered. Logically, a possible line of research would be limited to analyse the structure of the canning sector and its income statements using series obtained from the business registers, as well as the structure of the shipowning companies. However, the progressive internationalisation could be a relevant barrier to the success of this task.

CRediT authorship contribution statement

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

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Appendix

See Tables A.1–A.3.

Table A.1
Multivariate tests for mis-specification in the VAR models.

Variable relationships	No. of lags (k)	Autocorrelation (LM test) up to order 1	Autocorrelation (LM test) up to order 5	d_{max}
CAC/AC	4	0.75	2.14	1
CAC/ICQ	5	2.7	5.29	1
CAC/QIADF	2	3.44	7.01	1
CAC/QIANDF	3	6.5	4.35	1
CAC/QITA	2	4.17	9.04	1
CAC/QPCAB	2	3.94	7.59	1
CACSK/ICQ	5	2.29	5.26	1
CACSK/QIADF	4	2.1	9.34	1
CACSK/QITA	1	6.22	5.08	0
CACSK/QPCAB	2	7.26	6.07	1
CACYF/AC	1	6.33	2.62	1
CACYF/GTES	5	0.38	0.74	1
CACYF/QITA	4	9	6.05	1
CACYF/QPCAB	3	0.56	5.99	1
CCQ/ECQ	10	5.08	4.06	1
CCQ/GTES	6	4.74	1.83	1
CCQ/ICQ	13	5.75	8.27	1
CCQ/QPCAB	10	4.9	1.71	1
CFA1/AC	4	1.29	1.69	1
CFA1/TIM1	4	3.49	4.01	1
CFA1/TIN1	7	4.4	5.61	1
CT/ECQ	7	5.75	1.17	1
CT/GTEX	7	5.27	6.82	1
CT/QIADF	3	2.61	3.82	1
CT/QIANDF	3	4.47	2.4	1
CT/QITA	8	0.5	5.95	1
ECQ/AC	2	6.69	1.27	1
ECQ/ICQ	5	5.26	9.39	1
ECQ/QITA	1	5.81	2.98	1
ECQ/QPCAB	5	4.28	5.49	1
ECQ/VMT	8	1.96	5.54	1
EQV/CCQ	5	5.27	9.18	1
EQV/GTC	4	1.18	4.88	2
EQV/GTES	1	5.76	2.08	1
EQV/GTEX	4	0.72	1.91	1
EQV/QIADF	4	1.22	3.61	1
EQV/QIANDF	2	3.86	5.88	1
EQV/QITA	4	1.57	7.79	0
GTC/GTES	5	6.53	4.5	2
GTC/IQV	5	5.79	2.56	2
GTC/QPCAB	6	5.99	2.66	2
GTES/ICQ	3	2.74	2.37	1
GTES/QPCAB	6	3.54	6.66	1
GTEX/ICQ	8	8.22	2.17	1
ICQ/POEST	5	1.72	4.48	1
ICQ/QIANDF	5	2.97	9.11	1
ICQ/QPCAB	14	9.1	5.77	1
ICQ/VMT	9	7.13	1.1	1

(*continued on next page*)

Table A.1 (*continued*)

Variable relationships	No. of lags (k)	Autocorrelation (LM test) up to order 1	Autocorrelation (LM test) up to order 5	d_{max}
IQV/POEST	6	1.55	0.21	1
IQV/QIANDF	3	4.37	6.67	1
IQV/QPCAB	4	2.17	1.5	1
POEST/QIADF	1	9.2	8.12	1
POEST/QITA	7	7.78	3.79	1
POEST/TADRCN	2	1.54	1.62	1
PRGAS/CAC	3	1.4	1.23	1
PRGAS/CACSK	5	5.27	7.65	1
QIADF/TIM1	5	6.19	3.06	1
QIADF/TIN1	11	2	0.68	1
QITA/TIM1	5	5.05	3.11	1
QPCAB/QIANDF	6	4.42	3.6	1
QPCAB/QITA	1	4.76	3.73	1
TIM1/GTC	5	6.22	4.34	2
TIN1/AC	4	1.97	1.87	1
TIN1/TIM1	5	1.8	1.33	1
TS1/AC	2	1.76	4.47	1
TS1/TIN1	5	2.56	6.03	1
VMT/CT	5	2.67	3.65	1
VMT/GTEX	4	4.1	2.33	1
VMT/QIADF	6	3.48	1.9	1
VMT/QITA	6	3.99	2.34	0

Note: * significant at the 5% level.

Table A.2
Results of causality test based on bootstrap simulation techniques.

Null hypothesis	MWALD statistic	1% bootstrap critical value	5% bootstrap critical value	10% bootstrap critical value
CAC is not Granger-caused by AC	10.22*	17.82	11.28	8.79
AC is not Granger-caused by CAC	0.78	16.23	10.45	8.14
CAC is not Granger-caused by ICQ	26.56***	17.97	12.43	10.04
ICQ is not Granger-caused by CAC	12.97**	18.42	12.2	9.95
CAC is not Granger-caused by QIADF	16.45***	10.52	6.61	4.94
QIADF is not Granger-caused by CAC	1.85	10.71	6.63	4.85
CAC is not Granger-caused by QIANDF	2.68	13.23	8.45	6.55
QIANDF is not Granger-caused by CAC	8.36*	12.52	8.54	6.78
CAC is not Granger-caused by QITA	7.72**	11.03	6.62	4.96
QITA is not Granger-caused by CAC	2.03	11.13	6.76	5.1
CAC is not Granger-caused by QPCAB	0.45	10.47	6.38	4.8
QPCAB is not Granger-caused by CAC	8.22**	11.12	6.8	5.06
CACSK is not Granger-caused by ICQ	19.32***	18.14	12.5	9.89
ICQ is not Granger-caused by CACSK	18.1**	18.6	12.93	10.59
CACSK is not Granger-caused by QIADF	16.36***	15.29	10.58	8.38
QIADF is not Granger-caused by CACSK	4.56	16.11	10.73	8.41
CACSK is not Granger-caused by QITA	19.09***	7.87	4.5	3.13
QITA is not Granger-caused by CACSK	7.42**	7.91	4.24	2.96
CACSK is not Granger-caused by QPCAB	0.23	10.23	6.33	4.72
QPCAB is not Granger-caused by CACSK	12.63***	10.6	6.62	5
CACYF is not Granger-caused by AC	4.58**	8.59	4.06	2.73
AC is not Granger-caused by CACYF	5.65**	8.5	4.27	2.74
CACYF is not Granger-caused by GTES	13.69**	18.97	12.87	10.49
GTES is not Granger-caused by CACYF	2.75	17.86	12.35	9.99
CACYF is not Granger-caused by QITA	10.1*	16.55	10.88	8.6
QITA is not Granger-caused by CACYF	3.82	16.92	11.26	8.94
CACYF is not Granger-caused by QPCAB	7.03*	12.62	8.23	6.54
QPCAB is not Granger-caused by CACYF	6.74*	13.36	8.71	6.71
CCQ is not Granger-caused by ECQ	20.02	34.68	24.05	20.14
ECQ is not Granger-caused by CCQ	37.59***	31.62	22.35	18.54
CCQ is not Granger-caused by GTES	25.9***	20.56	14.28	11.81
GTES is not Granger-caused by CCQ	9.28	19.58	13.81	11.47
CCQ is not Granger-caused by ICQ	82.72***	46.68	31.75	25.72
ICQ is not Granger-caused by CCQ	78.04***	59.01	37.99	30.63
CCQ is not Granger-caused by QPCAB	29.56**	33.46	22.95	18.8
QPCAB is not Granger-caused by CCQ	33.7**	37.57	26.66	22.22
CFA1 is not Granger-caused by AC	1.98	15.91	10.78	8.53
AC is not Granger-caused by CFA1	23.21***	20.57	11.55	8.72
CFA1 is not Granger-caused by TIM1	12.74**	16.27	11.06	8.84
TIM1 is not Granger-caused by CFA1	3.41	15.8	10.64	8.39
CFA1 is not Granger-caused by TIN1	7.07	24.09	16.63	13.54
TIN1 is not Granger-caused by CFA1	18.6**	23.27	17.11	14.06
CT is not Granger-caused by ECQ	14.59*	22.84	15.44	12.75
ECQ is not Granger-caused by CT	22.14**	26.8	18.92	15.5

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Table A.2 (*continued*)

Null hypothesis	MWALD statistic	1% bootstrap critical value	5% bootstrap critical value	10% bootstrap critical value
CT is not Granger-caused by GTEX	11.1	31.2	20.46	16.15
GTEX is not Granger-caused by CT	22.51**	30.96	19.43	15.42
CT is not Granger-caused by QIADF	1.65	13.07	8.4	6.57
QIADF is not Granger-caused by CT	16.79***	13.31	8.81	6.86
CT is not Granger-caused by QIANDF	3.41	12.92	8.52	6.72
QIANDF is not Granger-caused by CT	7.5*	14.11	9.04	7.1
CT is not Granger-caused by QITA	14.33*	24.09	17.12	14.09
QITA is not Granger-caused by CT	18.3*	27.13	19.4	16.06
ECQ is not Granger-caused by AC	8.06**	12.01	7.27	5.2
AC is not Granger-caused by ECQ	0.12	12.25	6.98	5.02
ECQ is not Granger-caused by ICQ	18.1**	18.27	12.75	10.25
ICQ is not Granger-caused by ECQ	13.22**	19.06	13.16	10.5
ECQ is not Granger-caused by QITA	0.15	7.67	4.15	2.81
QITA is not Granger-caused by ECQ	5.05**	7.65	4.16	2.88
ECQ is not Granger-caused by QPCAB	22.41***	18.68	12.73	10.36
QPCAB is not Granger-caused by ECQ	12.37*	17.74	12.54	10.1
ECQ is not Granger-caused by VMT	18.9*	29.23	21.11	17.43
VMT is not Granger-caused by ECQ	20.5**	28.72	19.89	16.68
EQV is not Granger-caused by CCQ	4.27	17.68	12.24	10.05
CCQ is not Granger-caused by EQV	25.2***	18	12.37	9.99
EQV is not Granger-caused by GTC	7.39	18.57	11.46	9.13
GTC is not Granger-caused by EQV	9.15*	16.99	11.1	8.74
EQV is not Granger-caused by GTES	0.01	7.18	4.02	2.85
GTES is not Granger-caused by EQV	4.28**	7.48	4.1	2.85
EQV is not Granger-caused by GTEX	1.26	16.99	10.91	8.62
GTEX is not Granger-caused by EQV	10.52*	18.15	11.66	9.09
EQV is not Granger-caused by QIADF	15.99***	15.84	10.83	8.6
QIADF is not Granger-caused by EQV	8.99*	15.18	10.23	8.23
EQV is not Granger-caused by QIANDF	1	10.51	6.55	4.94
QIANDF is not Granger-caused by EQV	5.88*	11.38	7.07	5.26
EQV is not Granger-caused by QITA	15.67***	15.61	10.72	8.64
QITA is not Granger-caused by EQV	17.78***	17.44	11.73	9.37
GTC is not Granger-caused by GTES	4.07	18.54	12.51	10.1
GTES is not Granger-caused by GTC	13.62*	23.67	15.36	12.23
GTC is not Granger-caused by IQV	8.98	19.38	13.34	10.71
IQV is not Granger-caused by GTC	15.43**	20.52	13.85	11.08
GTC is not Granger-caused by QPCAB	21.61**	23.15	15.46	12.49
QPCAB is not Granger-caused by GTC	12.92*	23.27	15.96	12.81
GTES is not Granger-caused by ICQ	7.82*	13.14	8.4	6.63
ICQ is not Granger-caused by GTES	7.48*	12.73	8.46	6.64
GTES is not Granger-caused by QPCAB	18.98**	19.89	14.36	11.67
QPCAB is not Granger-caused by GTES	20.15**	21.51	14.73	11.96
GTEX is not Granger-caused by ICQ	28.88**	37.47	23.9	19.09
ICQ is not Granger-caused by GTEX	15.66	38.45	23.9	18.59
ICQ is not Granger-caused by POEST	15.22**	18.04	12.61	10.15
POEST is not Granger-caused by ICQ	1.87	18.24	12.33	9.92
ICQ is not Granger-caused by QIANDF	39.98***	20.16	13.42	10.86
QIANDF is not Granger-caused by ICQ	5.13	17.7	12.41	10.05
ICQ is not Granger-caused by QPCAB	116.27***	81.7	48.26	37.87
QPCAB is not Granger-caused by ICQ	79.78***	63.87	41.15	32.01
ICQ is not Granger-caused by VMT	24.09**	28.89	20.48	17.26
VMT is not Granger-caused by ICQ	18.3*	28.87	20.57	16.95
IQV is not Granger-caused by POEST	7.21	20.68	13.98	11.52
POEST is not Granger-caused by IQV	17.6**	20.7	14.61	11.96
IQV is not Granger-caused by QIANDF	6.1	13.33	8.57	6.72
QIANDF is not Granger-caused by IQV	8.35*	13.27	8.71	6.83
IQV is not Granger-caused by QPCAB	20.09***	16.78	11.22	8.9
QPCAB is not Granger-caused by IQV	6.87	15.75	10.39	8.39
POEST is not Granger-caused by QIADF	1.91	7.75	4.21	2.88
QIADF is not Granger-caused by POEST	4.31**	8.08	4.04	2.69
POEST is not Granger-caused by QITA	23**	23.3	16.11	13.13
QITA is not Granger-caused by POEST	7.42	22.8	15.83	13.08
POEST is not Granger-caused by TADRCN	0.44	10.8	6.51	4.84
TADRCN is not Granger-caused by POEST	9.76**	11.73	6.74	4.95
PRGAS is not Granger-caused by CAC	3.07	12.69	8.25	6.39
CAC is not Granger-caused by PRGAS	2.78	13	8.62	6.68
PRGAS is not Granger-caused by CACSK	11.58*	16.81	11.64	9.7
CACSK is not Granger-caused by PRGAS	2.3	18.12	12.4	10.18
QIADF is not Granger-caused by TIM1	25.61***	18.81	12.73	10.24
TIM1 is not Granger-caused by QIADF	7.16	17.98	12.46	10.05
QIADF is not Granger-caused by TIN1	34.18**	34.85	25.1	20.62
TIN1 is not Granger-caused by QIADF	5.85	35.73	24.98	20.51
QITA is not Granger-caused by TIM1	29.92***	18.25	12.71	10.26
TIM1 is not Granger-caused by QITA	6.3	18.23	12.7	10.18
QPCAB is not Granger-caused by QIANDF	15.38**	20.24	14.42	11.74
QIANDF is not Granger-caused by QPCAB	33.7***	20.23	14.1	11.6

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Table A.2 (*continued*)

Null hypothesis	MWALD statistic	1% bootstrap critical value	5% bootstrap critical value	10% bootstrap critical value
QPCAB is not Granger-caused by QITA	3.29*	7.96	4.22	2.88
QITA is not Granger-caused by QPCAB	3.25*	7.98	4.22	2.88
TIM1 is not Granger-caused by GTC	8.93	21.73	14.24	11.33
GTC is not Granger-caused by TIM1	21.97***	19.95	13.52	10.71
TIN1 is not Granger-caused by AC	12.21**	18.26	11.43	8.76
AC is not Granger-caused by TIN1	11.64**	17.91	11.36	8.79
TIN1 is not Granger-caused by TIM1	28.18***	18	12.3	10.2
TIM1 is not Granger-caused by TIN1	8.38	19.11	13.42	10.8
TS1 is not Granger-caused by AC	0.07	11.35	6.71	5.04
AC is not Granger-caused by TS1	9.53**	13.23	7.46	5.36
TS1 is not Granger-caused by TIN1	13.4**	18.95	12.92	10.44
TIN1 is not Granger-caused by TS1	8.72	18.29	12.7	10.39
VMT is not Granger-caused by CT	2.12	17.65	12.18	9.91
CT is not Granger-caused by VMT	9.44	21.65	15.01	12.18
VMT is not Granger-caused by GTEX	0.68	17.52	11.37	8.88
GTEX is not Granger-caused by VMT	12.29**	17.85	11.95	9.37
VMT is not Granger-caused by QIADF	14.46**	20.83	14.41	11.8
QIADF is not Granger-caused by VMT	10.73	19.95	14.31	11.87
VMT is not Granger-caused by QITA	17.67**	18.84	13.63	11.21
QITA is not Granger-caused by VMT	13.13	24.49	17.4	14.53

Note: The denotation ***, **, and * means that the null hypothesis on non-Granger causality is rejected at the 1%, 5% and 10% significance level, respectively.

Table A.3
Pearson and partial correlation coefficients for each of the significant causal relationships.

Direction of causality between nodes (variables)	Pearson correlation coefficient	Partial correlation coefficient	Eliminating the effect of
ICQ→CAC	0.649***	0.039	QPCAB, QIADF, QITA, AC
QPCAB→CAC	0.868***	0.372***	ICQ, QIADF, QITA, AC
QIADF→CAC	0.363***	0.349***	ICQ, QPCAB, QITA, AC
QITA→CAC	0.866***	-0.153	ICQ, QPCAB, QIADF, AC
AC→CAC	-0.678***	-0.522***	ICQ, QPCAB, QIADF, QITA
ICQ→CACSK	0.769***	0.217	QPCAB, QIADF, QITA
QPCAB→CACSK	0.904***	0.303**	ICQ, QIADF, QITA
QIADF→CACSK	0.731***	0.257*	ICQ, QPCAB, QITA
QITA→CACSK	0.888***	-0.039	ICQ, QPCAB, QIADF, AC
GTES→CACYF	0.719***	0.248*	QPCAB, QITA, AC
QPCAB→CACYF	0.621***	-0.309**	GTES, QITA, AC
QITA→CACYF	0.705***	0.456***	QPCAB, GTES, AC
AC→CACYF	-0.733***	-0.402***	GTES, QPCAB, QITA
ECQ→CCQ	0.968***	-0.9***	EQV, GTES, ICQ, QPCAB
EQV→CCQ	0.954***	0.072	ECQ, GTES, ICQ, QPCAB
GTES→CCQ	0.95***	-0.068	ECQ, EQV, ICQ, QPCAB
ICQ→CCQ	0.925***	0.97***	ECQ, EQV, GTES, QPCAB
QPCAB→CCQ	0.987***	0.983***	ECQ, EQV, GTES, ICQ
ECQ→CT	0.826***	-0.517***	GTEX, VMT, QITA
VMT→CT	0.924***	0.551***	ECQ, GTEX, QITA
QITA→CT	0.837***	0.122	ECQ, GTEX, VMT
CCQ→ECQ	0.968***	-0.849***	CT, GTES, ICQ, QPCAB, VMT, AC
CT→ECQ	0.826***	-0.132	CCQ, GTES, ICQ, QPCAB, VMT, AC
GTES→ECQ	0.913***	-0.106	CCQ, CT, ICQ, QPCAB, VMT, AC
ICQ→ECQ	0.932***	0.934***	CCQ, CT, GTES, QPCAB, VMT, AC
QPCAB→ECQ	0.967***	0.917***	CCQ, CT, GTES, ICQ, VMT, AC
VMT→ECQ	0.929***	0.272*	CCQ, CT, GTES, ICQ, QPCAB, AC
AC→ECQ	-0.428***	0.088	CCQ, CT, GTES, ICQ, QPCAB, VMT
CCQ→EQV	0.951***	0.219	GTC, GTEX, QIADF, QITA
GTC→EQV	0.959***	0.089	CCQ, GTEX, QIADF, QITA
GTEX→EQV	0.951***	0.101	CCQ, GTC, QIADF, QITA
QIADF→EQV	0.675***	0.04	CCQ, GTC, GTEX, QITA
QITA→EQV	0.903***	0.105	CCQ, GTC, GTEX, QIADF
EQV→GTC	0.959***	-0.047	GTES, IQV, QPCAB, TIM1
GTES→GTC	0.957***	0.559***	EQV, IQV, QPCAB, TIM1
IQV→GTC	0.937***	0.116	EQV, GTES, QPCAB, TIM1
QPCAB→GTC	0.991***	0.737***	EQV, GTES, IQV, TIM1
TIM1→GTC	-0.771***	-0.328**	EQV, GTES, IQV, QPCAB
CACYF→GTES	0.719***	0.741***	CCQ, GTC, ICQ, QPCAB
CCQ→GTES	0.95***	-0.103	CACYF, GTC, ICQ, QPCAB
GTC→GTES	0.957***	0.263*	CACYF, CCQ, ICQ, QPCAB
ICQ→GTES	0.87***	0.495***	CACYF, CCQ, GTC, QPCAB
QPCAB→GTES	0.94***	0.022	CACYF, CCQ, GTC, ICQ
EQV→GTEX	0.951***	0.403***	CT, ICQ, VMT, QIANDF
ICQ→GTEX	0.926***	0.494***	CT, EQV, VMT, QIANDF
VMT→GTEX	0.952***	0.403***	CT, EQV, ICQ, QIANDF
QIANDF→GTEX	0.925***	0.196	CT, EQV, ICQ, VMT

(continued on next page)

Table A.3 (*continued*)

Direction of causality between nodes (variables)	Pearson correlation coefficient	Partial correlation coefficient	Eliminating the effect of
CT→GTEX	0.896***	-0.148	EQV, ICQ, VMT, QIANDF
CAC→ICQ	0.649***	-0.078	CACSK, CCQ, ECQ, GTES, GTEX, POEST, QPCAB, VMT, QIANDF
CACSK→ICQ	0.769***	-0.052	CAC, CCQ, ECQ, GTES, GTEX, POEST, QPCAB, VMT, QIANDF
CCQ→ICQ	0.925***	0.946***	CAC, CACSK, ECQ, GTES, GTEX, POEST, QPCAB, VMT, QIANDF
ECQ→ICQ	0.932***	0.856***	CAC, CACSK, CCQ, GTES, GTEX, POEST, QPCAB, VMT, QIANDF
GTES→ICQ	0.87***	0.422***	CAC, CACSK, CCQ, ECQ, GTEX, POEST, QPCAB, VMT, QIANDF
GTEX→ICQ	0.926***	-0.226	CAC, CACSK, CCQ, ECQ, GTES, POEST, QPCAB, VMT, QIANDF
POEST→ICQ	-0.005***	0.045	CAC, CACSK, CCQ, ECQ, GTES, GTEX, QPCAB, VMT, QIANDF
QPCAB→ICQ	0.868***	-0.95***	CAC, CACSK, CCQ, ECQ, GTES, GTEX, POEST, VMT, QIANDF
VMT→ICQ	0.863***	-0.209	CAC, CACSK, CCQ, ECQ, GTES, GTEX, POEST, QPCAB, QIANDF
QIANDF→ICQ	0.901***	0.235	CAC, CACSK, CCQ, ECQ, GTES, GTEX, POEST, QPCAB, VMT
GTC→IQV	0.937***	0.123	POEST, QPCAB
POEST→IQV	0.304**	0.311**	GTC, QPCAB
QPCAB→IQV	0.941***	0.247*	GTC, POEST
ICQ→POEST	-0.005	-0.262*	IQV, QIANDF, QITA
IQV→POEST	0.304**	0.16	ICQ, QIANDF, QITA
QIANDF→POEST	0.11	-0.078	ICQ, IQV, QITA
QITA→POEST	0.316**	-0.124	ICQ, IQV, QIANDF
CAC→QPCAB	0.849***	-0.104	CACSK, CACYF, CCQ, ECQ, GTC, GTES, ICQ, IQV, QIANDF, QITA
CACSK→QPCAB	0.904***	0.061	CAC, CACYF, CCQ, ECQ, GTC, GTES, ICQ, IQV, QIANDF, QITA
CACYF→QPCAB	0.621***	0.123	CAC, CACSK, CCQ, ECQ, GTC, GTES, ICQ, IQV, QIANDF, QITA
CCQ→QPCAB	0.987***	0.969***	CAC, CACSK, CACYF, ECQ, GTC, GTES, ICQ, IQV, QIANDF, QITA
ECQ→QPCAB	0.967***	0.863***	CAC, CACSK, CACYF, CCQ, GTC, GTES, ICQ, IQV, QIANDF, QITA
GTC→QPCAB	0.991***	-0.17	CAC, CACSK, CACYF, CCQ, ECQ, GTES, ICQ, IQV, QIANDF, QITA
GTES→QPCAB	0.94***	0.259*	CAC, CACSK, CACYF, CCQ, ECQ, GTC, ICQ, IQV, QIANDF, QITA
ICQ→QPCAB	0.868***	-0.921***	CAC, CACSK, CACYF, CCQ, ECQ, GTC, GTES, IQV, QIANDF, QITA
IQV→QPCAB	0.941***	-0.286*	CAC, CACSK, CACYF, CCQ, ECQ, GTC, GTES, ICQ, QIANDF, QITA
QIANDF→QPCAB	0.903***	0.18	CAC, CACSK, CACYF, CCQ, ECQ, GTC, GTES, ICQ, IQV, QITA
QITA→QPCAB	0.927***	0.302**	CAC, CACSK, CACYF, CCQ, ECQ, GTC, GTES, ICQ, IQV, QIANDF
ECQ→VMT	0.929***	0.089	ICQ, QIADF, QITA
ICQ→VMT	0.63***	0.31**	ECQ, QIADF, QITA
QIADF→VMT	0.655***	-0.038	ECQ, ICQ, QITA
QITA→VMT	0.895***	0.28**	ECQ, ICQ, QIADF
CT→QIADF	0.663***	-0.077	ECQ, EQV, POEST, TIM1, TIN1
ECQ→QIADF	0.568***	-0.03	CT, EQV, POEST, TIM1, TIN1
EQV→QIADF	0.675***	0.195	CT, ECQ, POEST, TIM1, TIN1
POEST→QIADF	0.403***	0.236*	CT, ECQ, EQV, TIM1, TIN1
TIM1→QIADF	-0.412***	-0.39***	CT, ECQ, EQV, POEST, TIN1
TIN1→QIADF	-0.017	0.444***	CT, ECQ, EQV, POEST, TIM1
CAC→QIANDF	0.672***	-0.534***	CT, EQV, IQV, POEST, QPCAB, VMT
CT→QIANDF	0.767***	0.142	CAC, EQV, IQV, POEST, QPCAB, VMT
EQV→QIANDF	0.876***	0.24*	CAC, CT, IQV, POEST, QPCAB, VMT
IQV→QIANDF	0.849***	0.303**	CAC, CT, EQV, POEST, QPCAB, VMT
POEST→QIANDF	0.11***	-0.154	CAC, CT, EQV, IQV, QPCAB, VMT
QPCAB→QIANDF	0.903***	0.151	CAC, CT, EQV, IQV, POEST, VMT
VMT→QIANDF	0.886***	0.376***	CAC, CT, EQV, IQV, POEST, QPCAB
CACSK→QITA	0.888***	0.352***	CT, ECQ, EQV, QPCAB, TIM1
CT→QITA	0.837***	-0.338**	CACSK, ECQ, EQV, QPCAB, TIM1
ECQ→QITA	0.873***	-0.155	CACSK, CT, EQV, QPCAB, TIM1
EQV→QITA	0.903***	0.18	CACSK, CT, ECQ, QPCAB, TIM1
QPCAB→QITA	0.927***	0.425***	CACSK, CT, ECQ, EQV, TIM1
TIM1→QITA	-0.706***	0.001	CACSK, CT, ECQ, EQV, QPCAB
CACYF→AC	-0.733***	-0.751***	TIN1, CAF1
TIN1→AC	-0.255*	0.265*	CACYF, CAF1
CAF1→AC	-0.235*	-0.332**	CACYF, TIN1
POEST→TADRCN	-0.312**	-0.312**	
TIM1→TIN1	0.837***	0.436***	AC, CFA1
AC→TIN1	-0.255*	-0.273**	TIM1, CFA1
CFA1→TIN1	0.901***	0.596***	TIM1, AC
TIM1→CFA1	0.83***	0.83***	
AC→TS1	0.122	0.226*	TIN1
TIN1→TS1	0.312**	0.378***	AC
CAC→PRGAS	0.501***	0.037	CACSK
CACSK→PRGAS	0.508***	0.1	CAC

Note: The denotation ***, **, and * means that the null hypothesis on non-Granger causality is rejected at the 1%, 5% and 10% significance level, respectively.

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