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The ex-vessel market for tropical tuna in Manta, Ecuador. A new key player on the global tuna market

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Abstract :

This paper examines the Manta (Ecuador) market for landings and imports of skipjack, bigeye, and yellowfin tunas through estimation of an inverse almost ideal demand system. Skipjack landings and imports dominate the market. Manta tuna market prices show inflexible price responsiveness to changes in quantities of own species for all imports and landings except yellowfin imports. Simultaneously reducing landings and imports of all species increase vessel profits but is more than countered by economic welfare loss of supply chain firms, exporters, and consumers for a net decline in Ecuador's economic welfare. Results show two distinct but linked market segments: (1) one well integrated by price with mutually substitutable skipjack imports and skipjack, yellowfin, and bigeye landings and dependent on skipjack imports, and (2) a niche segment centered around yellowfin imports for processors. If the Bangkok market still retains primary global price leadership, it also responds to the growing Manta market.

Highlights

► Two distinct market segments for Manta Ecuador market for landings and imports of skipjack, bigeye, and yellowfin tuna. ► One segment centered around skipjack landings and imports and second centered around yellowfin imports. ► Skipjack, yellowfin, and bigeye landings readily substitute for one another. ► A reduction of landings and imports would increase fishers' revenues but reduce the overall economic welfare. ► Interests of vessel owners do not align with those of processors who require imports to meet the growing demand for tuna.

Keywords : Economic incentives, Tuna markets, Inverse almost ideal demand system, Price flexibility

The Ex-Vessel Market for Tropical Tuna in Manta, Ecuador

1. Introduction

Ecuador, with its fishing port Manta, is recognized as a key player on the global tuna market. Its yearly supply represents half a million tonnes (55% from landings and 45% from imports) valuing more than one billion USD. This South-American country has become the second or third largest producer in the world after Thailand, leader with 750,000 mt per year, and Spain, which is comparable in size with Ecuador but also closely linked to this country through foreign direct investment and trade (García del Hoyo et al. 2017, 2021). Ecuador is also total catch leader of the East Pacific Ocean tuna fishery, weighting 36% of total catch according to the Inter-American Tropical Tuna Commission in 2020, Mexico coming second with 24% (IATTC 2021). The national exports of tuna products have trebled for the last decade and represented 8.7% of Ecuadorian exports of non-oil products between 2010 and 2016 (Ministerio de Comercio Exterior 2017). Some 80% of production (frozen loins and canned tuna) are exported by containers to the European Union (59% of exports in 2016, mainly to Spain), the USA (13%) and Colombia (10%) to cite only a few major destinations (*Ibid*). The fishing and processing industry employs more than 100,000 workers in the country according to Nirsa, one of the largest canneries (www.nirsa.com). As fishing leader of the East-Pacific Ocean (EPO), Ecuador occupies a central position on the regional market. However, the regional market is deeply connected to the global trade network and therefore to the large catches of the West and Central Pacific Ocean imported massively by Thailand for processing (Jeon et al. 2008, Jiménez-Toribio et al. 2010).

Because the sustainability of fisheries relies on stringent management regulations and economic incentives, the responsiveness of ex-vessel prices to local landings and imports becomes of major interest for the management of EPO tuna stocks by the IATTC. In this respect, we analyze the extent to which the domestic supply does matter to form the Manta prices relative to other tuna markets, particularly to the worldwide leader Bangkok (Sun et al. 2017). The answer to this central issue has important economic and ecological consequences dealing with the strategies of fishers and processors targeting species and markets (Asche et al. 2015), because globalized trade can conflict with regional regulations of multi-species fisheries (Elsler et al. 2019). The relative price of species signals the best opportunities for fishers who remain bound by their own technology and access to natural stocks through a quota policy or available biomass and the existence of market outlets, domestically or internationally. In a multi-level market structure with low transaction costs, fishers may choose to sell locally or globally. Fishers have an influence on the local market but less or no influence on the global one. Hence, because of constant prices in the global market, increasing catches leads to increasing total revenues with growing catches sold on the global market. In contrast, in local markets, total revenues decline with increasing catches due to local demand which is flexible in prices and may deter any further increase of effort. Such dual market conditions on local and global markets may result in non-trivial bioeconomic equilibria according to the biological parameters of the population growth function (Elsler et al. 2019).

Several reviews of literature have been made about the price elasticity and flexibility of demand for fish and seafood products (Asche et al. 2007, Gallet 2009, Andreyeva et al 2010). They usually show a large variability of elasticity values between market segments by species, degree of processing, origin, wild or farmed origin, etc., without discussing the methodology selected for the demand model (ordinary or inverse, linear demand, transfer function, times series or cross-sectional data,…). The median value found in a meta-analysis of price elasticities of demand for fish made on 833 observations gave a figure of -0.79 (Gallet 2009). Demand can be deemed more price elastic for some specific group and less for others (e.g. -1.28 for salmon and -0.86 for shellfish products on average). A review of literature made on elasticity and flexibility coefficients estimated on the tuna ex-vessel markets gave an average value around (or a bit higher than) unity: from -0.93 to -1.55 for elasticity coefficients of cannery-grade tuna caught by purse-seiners, and between -0.82 to -1.28 for scale flexibility coefficients (Guillotreau et al. 2017). In other words, the demand for frozen tuna would be rather elastic, and prices would respond proportionately (or slightly less) to quantity changes. Conversely, at the end of the supply chain, the demand for canned fish was found rather inelastic to prices, at least on the European markets (elasticity values between -0.93 and -0.13; Jaffry and Brown 2008, García del Hoyo et al. 2017). Most processing and retailing industries in developed countries, where the highest records of tuna consumption are found, are highly concentrated. They may enjoy market power both downstream when bargaining prices with retailers but also upstream with their oligopsonistic advantage over the fishing sector. Consequently, pricing-to-market behaviours are not excluded whenever buyers are so poorly sensitive to price changes and if price transmission from fishers to eaters is imperfect (Daloonpate 2002).

This paper examines six related questions for the Manta Ecuador ex-vessel landings and imports market for tropical tunas, skipjack (*Katsuwonus pelamis*), bigeye (*Thunnus obesus*), and yellowfin (*Thunnus albacares*). First, what is the impact of changing target catch levels upon prices and harvesters' total revenue and hence incentives to reduce catches (Sun et al. 2017, Guillotreau et al. 2017)? Due to the large processing sector and substantial imports, the incentives of both the harvest and processing sectors must be evaluated and differentiated. Second, what is the impact of lower landings due to lower target catch levels upon the economic welfare of producers, all firms in the supply chain and consumers? Third, what are the relationships between the different species and how might these relationships potentially impact ex-vessel landings prices? Fourth, what is the relationship between landings and imports, and in particular how easily processors can substitute imports for landings? Fifth, how does the Manta market compare to the Bangkok market for price and revenue responses to changes in imports? Sixth, is there any seasonality in ex-vessel price responsiveness to changes in the timing of landings? The answer could potentially impact incentives to change the quarter of landings under a potential transferable effort credit program that could potentially replace the current extended time-area closure of 72 days instituted by the IATTC and that would allow vessels to freely fish and land throughout the Management Year.

To address these questions, we develop and econometrically estimate a six-good, six-equation inverse almost ideal demand system for the Manta market for skipjack, yellowfin, and bigeye landings and imports. The next section examines the data and the general pattern of landings, revenues or expenditures, and prices in this market. Section 3 specifies the inverse demand model and measures of price responsiveness and consumer and producer welfare. Section 4 discusses the empirical results. Section 5 concludes. Supporting Materials provide summary statistics of the data, and discusses the econometric estimation and its results.

2. Materials and Methods

2.1. Data

The Manta data are comprised of monthly landings quantities (metric tons) and expenditures (vessel revenues) of skipjack, yellowfin, and bigeye in Ecuador from vessels in the Eastern Pacific Ocean and imports of skipjack, bigeye, and yellowfin under the "Consumption Regime" 10 and Regime 21 (cost insurance freight, i.e. cif, values)[1] (data from the Central Bank of Ecuador for tuna imports, and quantity and price data from shipowners and processors for landings). All time series start in January 2013 and end in December 2020 (i.e. 8 years, or 96 months). The data set comprises three species, two supply sources (domestic landings and imports), in quantity and value over the period, i.e. 1,152 observations in overall. All values, initially in nominal US$ (since Ecuador uses this currency), were converted to real or inflation-adjusted December 2020 values using the monthly United States GDP Implicit Price Deflator (from the US Saint Louis Federal Reserve Bank).

Ex-vessel landing and import cif prices were formed as implicit prices with units of US$2020 December/mt. The Consumption Regime and Regime 21 imports for each species were aggregated using a geometric index with import expenditure shares as weights (a Cobb-Douglas aggregator function) that avoids potential separability inflexibility issues with a quadratic logarithmic utility function (Blackorby et al. 1978). Bangkok price data are derived from landings and revenue data from Thai Customs (https://www.customs.go.th) HS Codes for frozen imports are: Skipjack 030343, Yellowfin 030342, and Bigeye 030344. The exchange rate is from US Saint Louis Federal Reserve Bank (monthly average of daily rates). The cif price is converted from kg to mt and then converted to US$2020 December values.

There were missing prices (but not quantities) of landed bigeye during February - April 2016 and April 2017. The number of observations for actual estimation dropped from 96 to 91 due to missing values across all product categories (determined by missing revenues and prices). The figures below used all periods' data, so that some periods may have one or more variables missing.

2.2. Overview of the Manta Market

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[1] Under Regime code 10 ("*Importación para el consumo*", i.e. "for consumption"), commodities are definitively imported and can circulate across the national territory. Under Regime code 21 (MR21) of the National Customs Services ("*Admisión temporal para perfeccionamiento activo*", i.e. "Temporary Admission Regime to re-export"). Under this regime, commodities can be imported for one year with possible extension in the country for further processing, assembling, repair, etc. before re-exports (typically the case of loins being processed and re-exported as canned fish).

Ecuador plays a central role in the EPO fishery managed by IATTC. With a fleet of 114 purse-seiners, it represents 43.7% of the EPO fleet and 34.4% by the volume of well capacity (IATTC 2021). Over the last decade, this country had 41% of the catch tonnage recorded by IATTC, far ahead of other Latin American countries such as Mexico (23%), Panamá (10%), Venezuela (7%) and Nicaragua (3%) (Ministerio de Comercio Exterior 2017). The 20 fish processors have a total processing capacity of more than 500,000 tons of raw fish into canned tuna (80%) and tuna loins (20%), which is concentrated in three provinces (Guayas, Manabí, Santa Elena). The largest processing share lies in the province of Manabí where the port of Manta is located. Because the domestic catch (269,436 mt in 2020) is not enough to cover the requirements of the export demand, the processors import nearly as much imports (206,786 mt) of raw materials caught by foreign-flagged fleets landing in Manta or by freight from overseas.

The Manta market is dominated by expenditures on skipjack landings and imports (mean share of all expenditures of 61.91%) since the purse seine fisheries flagged in Ecuador and Panama predominately set on floating objects, and are largely considered skipjack fleets (Figure 1). Other countries, such as Colombia and Venezuela, set on both dolphins and floating objects, and also land in Manta although not exclusively. All vessels set on free schools of tuna (unassociated sets), which are less important than floating object sets by catch volume and value, and are considered to be more opportunistic, cost more, and have higher probabilities of set failure. Yellowfin landings in Manta, while fetching a higher ex-vessel price, are secondary to skipjack landings by volume and value. (Table A1). Bigeye in floating object sets is for most vessels bycatch to skipjack, although bycatch may be targeted with deeper sets on floating objects.

Skipjack landings and imports dominate expenditure shares, confirming the reputation of Manta as a skipjack port. The overall mean expenditure share of each product is: (1) skipjack landings, 36.3%, (2) skipjack imports, 25.6%, (3) yellowfin imports, 14.6%, (4) yellowfin landings, 9.9%, (5) bigeye landings, 8.7%, (6) bigeye imports, 4.9%. Collective expenditures on landings and imports are: (1) skipjack 61.9%, (2) yellowfin 24.5%, and (3) bigeye 13.6% (Appendix A2).

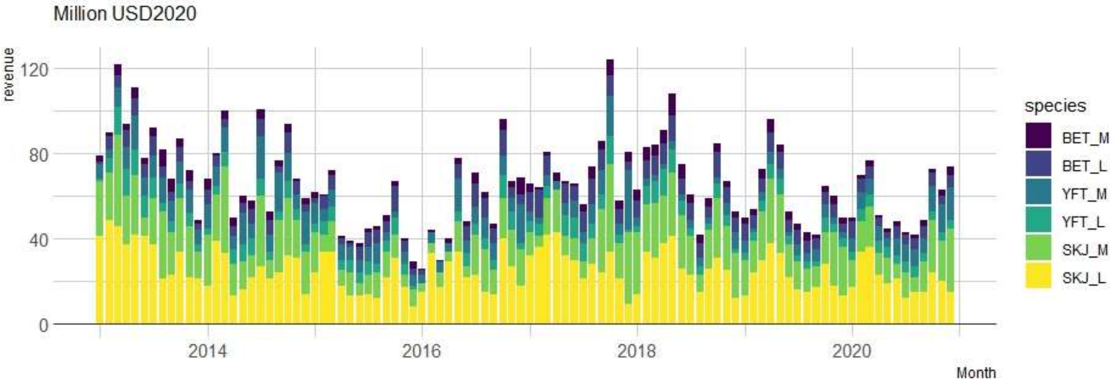

Figure 1. Ecuador monthly expenditure by species and origin 2013:1-2020:12

Note: BET = Bigeye tuna, SKJ = skipjack, YFT = Yellowfin tuna; L denotes domestic landings and M imports.

Monthly expenditures by species fluctuate both monthly and annually (Fig. 1). Skipjack imports (SKJ_M) expanded considerably in the second quarter of 2017 as skipjack landings (SKJ_L) fell off, before declining as skipjack landings increased again. Processors appear to demand a fairly steady supply of skipjack regardless of sources. In 2020, yellowfin imports (YFT_M) increased. Monthly expenditure shares (%) of landings and imports also fluctuate monthly and annually (Fig. 2). The relative importance of landings to imports fluctuates over time, with imports growing in relative importance in 2020. Since skipjack dominates by species, and as we demonstrate below, imports may well explain any decline in ex-vessel landings prices.

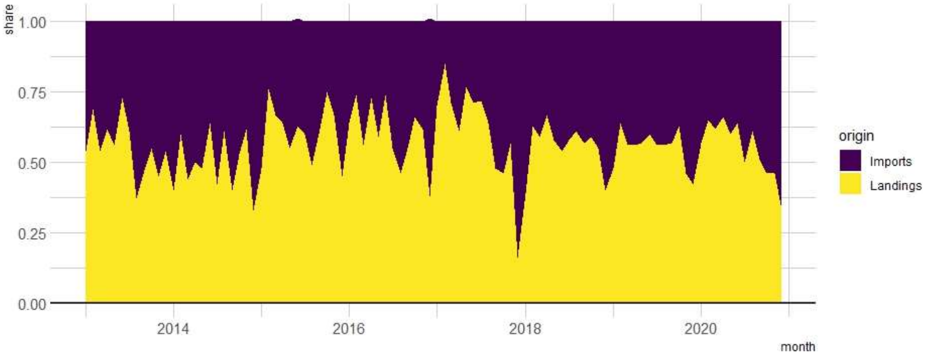

Figure 2. Monthly expenditure shares of landings and imports, 2013:01-2020:12

Real prices fluctuate monthly, displaying a secular decline from January 2013 to a low around the end of 2015 and early 2016, then rising through the last months of 2017, after which skipjack landings (SKJ_L) and bigeye landings (BET_L) and skipjack import (SKJ_M) and bigeye import (BET_M) prices decline, with especially pronounced declines in skipjack landings and imports prices. Yellowfin landings prices (YFT_L) level out and yellowfin import prices (YFT_M) rise noticeably above the others (Figure 3). The yellowfin import price spiked in December 2019 (dominated by the price for the Management Regime imports), and there were missing values for yellowfin imports from the Management Regime, all of which help explain the unusual yellowfin import price and revenue pattern.

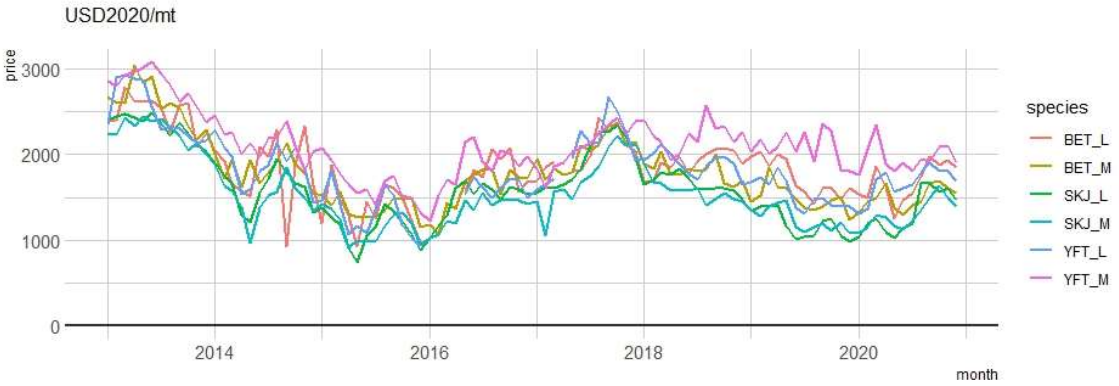

Figure 3. Ecuador Monthly Prices (USD2020/mt)

Note: Import prices are geometric means of Consumption and MR21 Regimes cif prices. BET = Bigeye tuna price, SKJ = skipjack price, YFT = Yellowfin tuna price; L=domestic landings and M=imports.

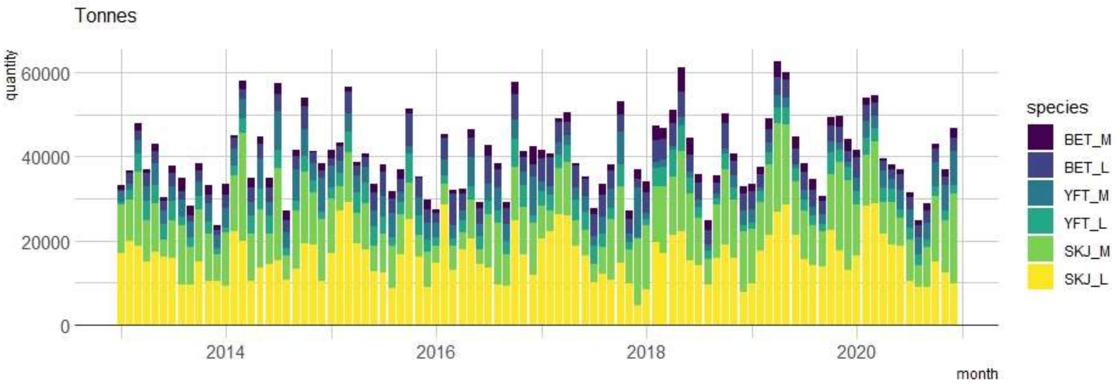

Figure 4. Ecuador Monthly Quantities Landed and Imported by Species 2013-2020

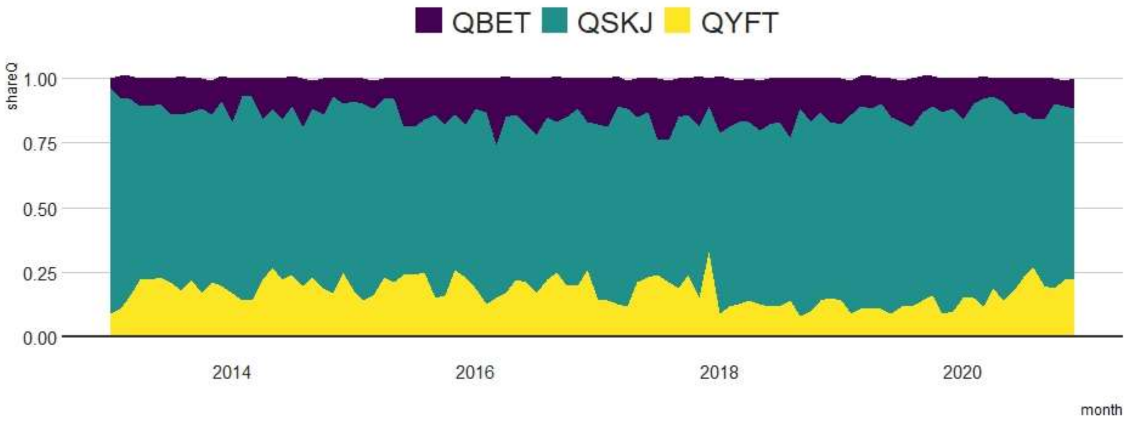

Figure 5. Ecuador Quantity (landings and imports) shares by species 2013:1-2020:12

Note: Landings and imports are linearly aggregated by species.

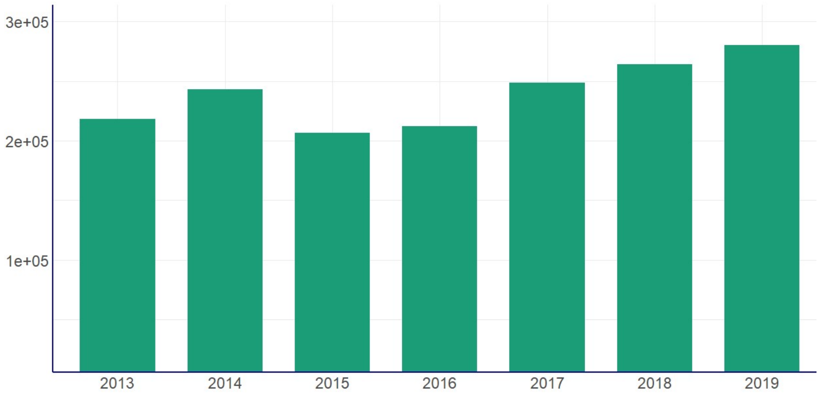

Figure 6. Ecuador Exports of Canned and Loined Tuna (mt)

Source: Ecuador National Customs services

Figure 4 depicts fairly stable but fluctuating volumes and shares of monthly quantities landed and imports until 2018 when skipjack imports increased. Figures 4 and 5 demonstrate skipjack's central importance to the Manta market for tropical tunas (61.91% of supply over the period). Bigeye and yellowfin quantities stay similar over the years, with yellowfin landings more frequently exceeding bigeye landings, including during 2020. Ecuador exports (mt) generally increased over 2013 to 2019 (Fig. 6). Filling in the demand gap between domestic landing supply and domestic market and export demand may require increasing imports (Fig. 4), which are dominated by skipjack imports even though skipjack landings have also moderately increased in later months.

3. Theory and Calculations

To obtain an adequate demand model specification for our data set, several decisions of binary alternatives should be made. The demand function can be linear or logarithmic, ordinary or inverse, Marshallian (uncompensated) or Hicksian (compensated), detailed or aggregated, static or dynamic, final or derived, etc. (Eales et al., 1997; Sun et al. 2017, 2019). In this regard, an extensive overview of studies on the demand structure for fish and seafood products is provided by Asche et al. (2007) and a meta-analysis of fish demand studies is carried out by Gallet (2009). The almost ideal demand system (AIDS) of Deaton and Muellbauer (1980) is the most prevalent functional form in demand systems (Asche et al., 2007; Gallet 2009).

In this study, an inverse demand model has been used. In many empirical demand studies, it is a frequent assumption that prices predetermined at the market level may be irrational, particularly for items that are perishable and vulnerable to environmental production lags, according to Barten and Bettendorf (1989). Much of the literature on the demand for fish and seafood products has used this approach: Barten and Bettendorf (1989), Burton (1992), Eales et al. (1997), Jaffry et al. (1999), Beach and Holt (2001), Holt and Bishop (2002), Nielsen (2004), Park et al. (2004), Kristoffersson and Rickertsen (2004, 2007), Lee and Kennedy (2008), Dedah et al. (2011), Thong (2012), Hammarlund (2015), Huang (2015), Sjöberg (2015), Moore and Griffiths (2018), Wong and Park (2018), Schrobback et al. (2019), Gordon (2020), among others. Additionally, the inverse demand function has been used in some studies about tuna such as Chiang et al. (2001), Sun et al. (2017), Gordon and Hussain (2015) and Sun et al. (2019).

The instrumental variables approach is another option to estimate demand (Tokunaga, 2017). The fact that this approach can address the endogeneity issue -which arises because the price and quantity data are the outcome of the market clearing process- is one of its advantages. This approach has been used, for example, by Graddy (1995, 2006), Angrist et al. (2000), Jang et al. (2021), Hammarlund et al. (2022), among others. Also, this approach was employed in various tuna research studies such as Tokunaga (2017). As Jang et al. (2021) state, this method is used less frequently than other methods for the estimation of fish and seafood demand.

According to Eales and Unnevehr (1993) and Rickertsen (1998), the endogeneity of prices and quantities can be tested by using a Durbin-Wu-Hausman test. This test allows investigating whether quantities or prices can be considered as predetermined or both are endogenous. Therefore, if quantities are endogenous and prices predetermined, an ordinary demand model is appropriate. In contrast, if quantities are predetermined and prices endogenous, an inverse demand model is appropriate. Finally, if both prices and quantities are endogenous, instrumental variables techniques are adequate to estimate either model. In this study, as can be seen in section A3.1. Preliminary Analysis, quantities are found to be predetermined. Consequently, an inverse demand model is chosen.

The Inverse Almost Ideal Demand System (IAIDS) can be specified as (Eales and Unnevehr 1994):

$$w_i = \alpha_i + \sum_{k=2}^{4} \alpha_k D_k + \sum_{j=1}^{6} \gamma_{ij} lnQ_j + \beta_i lnQ, \qquad (1)$$

where $w_i =$ expenditure share of landed catch or import $i = 1,2,3,\ldots,6$, $Q_1 =$ quantity of Ecuadorian landed skipjack (mt), $Q_2 =$ quantity of landed bigeye from the EPO (mt), $Q_3 =$ quantity of landed yellowfin from the EPO (mt), $Q_4 =$ quantity of skipjack imports (mt), $Q_5 =$ quantity of bigeye imports (mt), $Q_6 =$ quantity of yellowfin imports of yellowfin (mt). Each import variable, $Q_i, i = 4,5,6$, was formed as a geometric index: $ln\ Q_i = \sum_{n=1}^{2} m_n lnQ_n$, where $n = 1$ corresponds to Consumption Regime imports and $n = 2$ corresponds to MR21 imports and m_n denotes the corresponding expenditure share. lnQ is an aggregate quantity index (mt), where $lnQ = \alpha_0 + \sum_{j \neq i} \alpha_j lnQ_j + 0.5 \sum_{i=1}^{M} \sum_{j \neq i} \gamma_{ij} lnQ_i lnQ_j$ is a translog aggregate quantity index. Use of lnQ makes estimation of (1) nonlinear because it depends on unknown parameters that should be estimated. Therefore, a replacement for the quantity index previously defined that do not rely on unknowable parameters such as Stone's quantity index, would be useful and would allow us to linearise the system. In this regard, to simplify and give an index invariant to units of measurement, Moschini (1995) suggests that a geometric index with fixed weights (here historical averages) replace lnQ, giving a Divisia volume index: $lnQ_t = \sum_{i=1}^{M} w_i^0 lnQ_i$. $D_k =$ dummy variable for quarters of the calendar year, $k = 2,3,4$, and ln denotes natural logarithm. Quarterly rather than monthly dummy variables are specified to reduce multicollinearity and provide more precise estimates through smaller standard errors.

Restrictions on the demand system to be consistent with theory are: (1) Cournot and Engel aggregation: $\sum_{i=1}^{6} \alpha_i = 1, \sum_{k=2}^{4} D_k = 0, \sum_{j=1}^{6} \gamma_{ij} = 0, \sum_{i=1}^{6} \beta_i = 0$, (2) Homogeneity: $\sum_{j=1}^{6} \gamma_{ij} = 0$, and (3) Symmetry: $\gamma_{ij} = \gamma_{ji}, \forall i, j = 1,2,\ldots,6$. These restrictions allow identifying parameters of the yellowfin import expenditure share equation which was dropped from the estimated system of equations: $\alpha_6 = 1 - \sum_{i=1}^{5} \alpha_i,\ \beta_6 = 1 - \sum_{i=1}^{5} \beta_i$ and $\gamma_{i6} = 0 - \sum_{j=1}^{5} \gamma_{ij},\ i = 1,2,\ldots 6$.

3.1. Price and Scale Flexibilities

The uncompensated cross-quantity price flexibility is given by the following one quantity-one price equation (Eales and Unnevehr 1994, Kim 1997):

$$f_{ij} = \frac{\partial lnP_i}{\partial ln \ \ _j} = \frac{\gamma_{ij} + \beta_i [w_j - \beta_j ln \ \ ]}{w_i}, i \neq j \qquad (2)$$

Commodities i and j are gross q-complements if $f_{ij} > 0$ (Hicks 1956, Sato and Koizumi 1973). Hence, a one percent increase in the quantity of commodity j increases the price of commodity i by more than one percent with all other quantities held constant. More of commodity i makes commodity j more attractive and increases the price a buyer is willing to pay for it. Commodities i and j are gross q-substitutes if $f_{ij} < 0$. Hence, a one percent increase in the quantity of commodity j decreases the price of commodity i with all other quantities held constant. More of commodity i makes commodity j less attractive and reduces the price a buyer is willing to pay for the same quantity of commodity j. $f_{ij} = 1$ corresponds to a unit flexibility. Larger absolute values of cross-price flexibilities, $\left|f_{ij}\right|$, indicate larger effects.

Q-substitution for product i means that with a quantity increase, buyers substitute away from the product to another. The q-substitution counters the impact of the product's scale flexibility, leading to the uncompensated own price flexibilities (capturing the combined effect of compensated price and scale flexibilities) smaller in value than the scale flexibilities.

Uncompensated own-price flexibilities represent the proportional change in own price P_i with a change in own quantity Q_i (Anderson 1980). They combine the effect of the compensated price and scale flexibilities, i.e. they account for both the price and scale (expansion in same proportion) effects. The uncompensated own-quantity price flexibility is given by the following one quantity-one price equation (Eales and Unnevehr 1994):

$$f_{ii} = \frac{\partial lnP_i}{\partial lnQ_i} = -1 + \frac{\gamma_{ii}+\beta_i[w_i-\beta_i lnQ]}{w_i} \tag{3}$$

The uncompensated own-quantity price is flexible to quantity / unitary flexible / inflexible as $|f_{ii}|$ > / = / < 1, so that own prices demonstrate responses proportionately larger / equal / smaller than own quantity changes (allowing for both changes in the scale of consumption and responses to price in consumption) (Anderson 1980). Inflexible own-quantity prices ($|f_{ii}| < 1$) create weak producer incentives to reduce supply for product i, because a 1% fall in supply leads to a less than 1% price increase and hence a decline in total revenue from the product. Inelastic own-quantity flexibilities also imply that corresponding price elasticities of demand are elastic (Reciprocals of the matrix of price flexibilities provide lower bound on p-elasticities of substitution between products in direct demand (Deaton 1979)). Similarly, flexible own-quantity prices ($|f_{ii}| > 1$) create strong producer incentives to decrease supply for that product i, because a 1% decrease in supply generates a greater than 1% increase in price and thereby increase in total revenue.

The scale flexibility f_i gives the change in ex-vessel prices following a proportional change in all quantities supplied when the movement from one consumption bundle to another can be decomposed into a utility-constant substitution and then a proportionate change in all quantities supplied (Anderson 1980). The sum of the uncompensated price flexibilities gives the scale flexibility (Kim 1997): $\sum_j f_{ij} = f_i$. An absolute value of the scale flexibility greater than unity, i.e. $|f_i| > 1$, is scale flexible. Prices would decrease more rapidly than the increase in aggregate supply for all species landed or imported, so that producer revenues would fall. An absolute value of the scale value less than unity, i.e. $|f_i| < 1$, is scale inflexible. Prices would decrease proportionately less after an increase in aggregate supply (landings and imports), so that producer revenues would climb. An absolute value of unity, i.e. $|f_i| = 1$, gives constant producer revenue with a change in the scale of landings and imports. $|f_i| = 1$ also indicates preference is homothetic, so that sales shares are constant and consumption of the product is independent of the total expenditure level (Barten and Bettendorf 1989). Scale flexibilities smaller than –1 ($f_i <$

-1), thus considered flexible for necessary goods (e.g. $f_i = -2.0$), so that as consumption of all landings and imports increase by 1%, the revenue of necessities declines more than proportionately. By symmetry, scale inflexible values ($-1 < f_i < 0$) are observed for luxury goods (e.g. $f_i = -0.5$), so that revenues of luxuries decline less than proportionately (Eales and Unnevehr 1994). When scale flexibilities are zero, i.e. $f_i = 0$, the uncompensated and compensated own-quantity price flexibilities coincide.

The scale flexibility is (Eales and Unnevehr 1994):

$$f_i = -1 + \frac{\beta_i}{w_i}. \tag{4}$$

Consistency with theory requires the flexibilities to satisfy the following aggregation relationships: $\sum_{j=1}^{6} f_{ij} = f_i$ (homogeneity), $\sum_{i=1}^{6} w_i f_{ij} = -w_j$ (Cournot), and $\sum_{i=1}^{6} w_i f_i = -1$ (Engel) (Anderson 1980, Eales and Unnevehr 1994). The total change in prices associated with an increase in one quantity can be decomposed into substitution and scale effects.

The (Antonelli) compensated price flexibilities can be computed directly from the (Marshallian) uncompensated price flexibilities as (Anderson 1980, Eales and Unnevehr 1994): $f_{ij}^{c} = f_{ij} - w_i f_i$. This represents the decomposition of the latter into the former compensated price flexibility and scale flexibility, corresponding to the Antonelli decomposition of inverse demand (Antonelli 1886, Cornes 1992). The compensated price flexibilities were directly evaluated by Park et al. (2004):

$$f_{ii}^{c} = \frac{\gamma_{ii}}{w_i} + w_i - 1. \tag{5}$$

$$f_{ij}^{c} = \frac{\gamma_{ij}}{w_i} + w_j, i \neq j\ . \tag{6}$$

Other indicators can be mobilized to assess differently the complementarity and substitutability of products by pairwise comparisons, such as Morishima and Allais coefficients (Barten and Bettendorf 1989, Kim 1997). Both are extensively presented with their empirical outcomes in Appendix A1.

3.2. Economic Welfare Impacts

The economic welfare impacts of a reduction in total quantity landed or imported can be evaluated by calculating quantity-based compensating (QCV) and equivalent (QEV) variations, which are measured as areas below inverse Hicksian compensated demand curves (Kim 1997). QCV is the additional normalized expenditure required for the consumer to be restored to the initial utility level U^0 when facing the bundle of quantities $\boldsymbol{Q}^1$ and QEV is the additional normalized expenditure required for the consumer to achieve final utility level U^1 when facing the bundle of quantities $\boldsymbol{Q}^0$. To the extent that the inverse demand curves are equilibrium demand curves, the economic welfare assessment captures both consumer and producer surplus of harvesters and firms in the supply chain (Just et al. 2004).

The estimated compensated own-price flexibilities from (5) are used to calculate QCV and QEV. Consumer surplus is evaluated from Marshallian uncompensated inverse derived demand curves. The Hicksian and Marshallian measures differ by the proportional change in all quantities, the scale effect. Supplementary Materials A.1 further discusses economic welfare estimation, including the estimating equation.

4. Empirical Results

The Supplementary Information's preliminary econometric analysis of the expenditure share equations reject serial correlation and endogenous regressors (Appendix A3). It also reports the inverse AIDS parameter estimates, estimated by maximum likelihood using TSP, and hypothesis tests for final model specification.

Scale flexibilities are reported in the second column of Table 1, uncompensated own-quantity prices flexibilities in the diagonal elements, and uncompensated cross-quantity price flexibilities in the off-diagonal elements. Table 1 is arranged by row for each quantity and corresponding price by column. Rows depict the species equations and quantities while columns represent corresponding own-and cross-quantity price flexibilities. For example, for skipjack landings in the first row, the cell corresponding to the column scale flexibility is the skipjack landings scale flexibility, the cell corresponding to the skipjack landings price column is the uncompensated own-quantity price flexibility, and the cell corresponding to the bigeye landings price column is the uncompensated cross-quantity price flexibility between skipjack landing quantity and bigeye landing price.

One of the six questions this paper poses is seasonal patterns that could have implications for the timing of landings should the current 72-day closure be replaced by a transferable day credit program. The quarterly dummy variables are statistically significant as a group, indicating that quarter of landings does impact price and expenditures (revenues) (Supplementary Information, Table A2). Skipjack landing expenditures (39% of all expenditures) are marginally highest in the first quarter, bigeye landing expenditures (10% of all expenditures) are marginally highest in the third quarter, and yellowfin landing expenditures (8% of all expenditures) are marginally highest in the second quarter. Given the importance of skipjack landings to total expenditures (revenues received by vessels), the ability to fish year-round would have a small positive impact upon vessel revenues.

Table 1. Scale and Uncompensated Own-quantity and Cross-quantity Price Flexibilities

	Scale Flexibility	Uncompensated Price Flexibility					
		Skipjack Landing Price	Bigeye Landing Price	Yellowfin Landing Price	Skipjack Import Price	Bigeye Import Price	Yellowfin Import Price
Skipjack Landings	-1.2367*** (0.034399)	-0.7493*** (0.0625)	-0.0971*** (0.0160)	-0.1368*** (0.0145)	-0.2880*** (0.0261)	-0.1513*** (0.0126)	0.0924*** (0.0332)

Bigeye Landings	-1.0376*** (0.0044)	-0.3343*** (0.0861)	-0.2750*** (0.0707)	-0.1170* (0.0629)	-0.2310*** (0.0500)	-0.0291 (0.0231)	- 0.0514 (0.0673)
Yellowfin Landings	-1.0533*** (0.0608)	-0.4811*** (0.0611)	-0.1148*** (0.0521)	-0.3140*** (0.0700)	-0.1121*** (0.0460)	-0.0475*** (0.0231)	0.0186 (0.0611)
Skipjack Imports	-1.0478*** (0.0544)	-0.2333*** (0.0612)	-0.0800*** (0.0133)	-0.0823*** (0.0162)	-0.4124*** (0.0360)	-0.0491*** (0.0125)	-0.0854* (0.0487)
Bigeye Imports	-0.9935*** (0.0947)	-0.2895*** (0.1189)	-0.0473* (0.0441)	-0.0765 (0.0519)	-0.2412*** (0.0585)	-0.2019*** (0.0584)	-0.1370 (0.0866)
Yellowfin Imports	-0.1781*** (0.0121)	0.5986*** (0.0895)	0.0439 (0.0469)	0.1130*** (0.0485)	0.0724 (0.0997)	-0.0063 (0.0340)	-1.7954*** (0.0379)

Note: Linearized standard errors in parentheses. Uncompensated scale and price flexibilities calculated at sample mean.
*** for 1% level of significance, ** for 5%, * for 10%. Bigeye landings and bigeye imports scale flexibilities not statistically significantly different than one (Table A3.2). Uncompensated = Marshallian. Color gradient by decreasing order of magnitude.

4.1. Scale flexibilities

cale flexibilities indicate whether a change in total quantity landed proportionately changes expenditures (revenues) more or less and potential impact upon incentives. When tuna populations exhibit a comparatively extensive flat area at the top of their yield-effort curves, they can be exploited heavily for long periods of time before biomass begins to decline below levels that support Maximum Sustainable Yield (MSY). Then for these fisheries, the nature of the ex-vessel price response to changes in catch levels (which determine aggregate supply) impacts total revenues (Sun et al. 2017, Guillotreau et al. 2017). Depending upon the responsiveness of tuna demand and ex-vessel prices to declines in target catch levels, catch reductions can lead to prices that increase proportionately more than the fall in quantity supply, leading to revenue increases. This statement holds under the specific assumptions of effective markets where equilibrium prices and quantities can adjust in the long run. The global tuna market for canneries has proven sufficiently competitive to allow for such adjustments (Jeon et al. 2008, Jiménez-Toribio et al. 2010, Guillotreau et al. 2017).

Reduced fishing might not only increase revenues but also lower costs and raise profits (Sun et al. 2017). Cost reductions can stem from the decrease in fishing effort and hence lower input usage but also the marginal stock effect whereby lower catch limits rebuild stocks that in turn lower search and harvest costs (Clark 1990). Should prices rise proportionately more than quantities decline, the increased revenues could potentially contribute to financing vessel buybacks to reduce the overcapacity that plagues the EPO.

The scale flexibilities all have the negative expected sign, are significantly different from zero (Table 1) and -1, i.e. $|f_i| \neq 1$ at 1% except for bigeye landings and bigeye imports (Table A3.2). The prices for skipjack and yellowfin landings and skipjack imports are all (slightly) scale flexible, since the estimated values are less than -1 i.e. $-1 > f_i, |f_i| > 1$. Price falls proportionately more than increases in aggregate supply (landings and imports), and total revenue falls. These necessary goods form the core of the Ecuadorian tuna economy (vessels, processors, exports, consumers and total tuna volume and revenues). Symmetrically, any reduction of landings or imports results in higher incomes for fishers, hence an incentive for them to reduce the global fishing effort or imports.

The unitary scale flexibilities for bigeye landings and imports indicate that a quantity change in bigeye landings or imports perfectly offset an opposite move in their prices, keeping total revenue constant. Thus, bigeye consumption of either landings or imports is independent of the total expenditure level. These bigeye unitary scale flexibilities are also very close to the slightly scale-flexible responses for skipjack landings and imports and yellowfin catches, which supports the notion of bigeye, as slight q-substitutes to these products (Section 4.2.2.) and forming part of the global market for cannery-grade species caught by purse-seiners. These results for bigeye likely arise because bigeye catch is mostly bycatch to skipjack in floating object sets, although bigeye is targeted by longliners and by some purse seiners (that set "extra deep").

In contrast, yellowfin import inverse demand and prices are scale rigid: a 1% increase in aggregate quantity supplied decreases prices by just 0.18%. This is evidence that yellowfin import prices are set in other markets. It is also evidence that yellowfin imports, as a luxury good ($-1 < f_i < 0$) in the Manta market, are a distinct market segment from other tuna. This finding conforms with our intuition: the Spanish market, where yellowfin is particularly appreciated by domestic consumers (García del Hoyo et al. 2017), is an important outlet for Manta yellowfin tuna.

Because skipjack landings and imports dominate the quantities and revenues (expenditures) of all species combined with 62% of all expenditures (Table A2, Figures 1, 4, 5), their scale-flexible responses suggest that reducing the IATTC sustainable target catches of skipjack, bigeye, and yellowfin would increase fishers and processors' revenues. However, the outcome would not be so clear because imports also contribute to the quantity traded in Manta that forms the regional price. Reminding that the scale flexibility is the sum of uncompensated flexibilities ($\sum_j f_{ij} = f_i$; Kim 1997), we can see that the landings of skipjack contribute more to the scale flexibility than the imports of skipjack (36% vs 26% by expenditure share). In other words, prices respond more to regional landings than they do to imported fish. To some extent, processors can substitute skipjack imports for landings (see Section 4.2.2. below) – although import prices tend to exceed landings prices for all species. The substitution of skipjack imports for landings dampens processor disincentives from reduced landings, but vessel owners are even more likely to accept lower landings.

4.2. Price flexibilities

4.2.1. Uncompensated (Marshallian) own-quantity price flexibilities

The uncompensated (Marshallian) own-quantity price flexibilities (Table 1 diagonal elements and Fig. 7), which capture the combined effects of compensated own-quantity price and scale flexibilities, are all negative as expected and are statistically significant at 1%. All but yellowfin imports are price inflexible to their own quantity consumed (i.e.$|f_{ii}| < 1$). Thus, with the exception of yellowfin imports, a 1% fall in supply for any species-product form alone leads to a less than 1% increase in own price and total revenue, thereby generating no producer incentives to reduce supply of that product (since the lower catch would not be proportionately compensated for by higher revenue). These inelastic uncompensated own-quantity price flexibilities also imply that the corresponding uncompensated own-price elasticities of direct demand are greater than unity in absolute value (Deaton 1979), i.e. the quantity directly demanded is highly responsive to own price changes, most likely due to the generally high substitution of products in direct demand. With the exception of yellowfin imports, the uncompensated own-quantity price flexibilities are smaller in absolute value than their corresponding scale elasticities, which counter the impact of the corresponding scale flexibility.

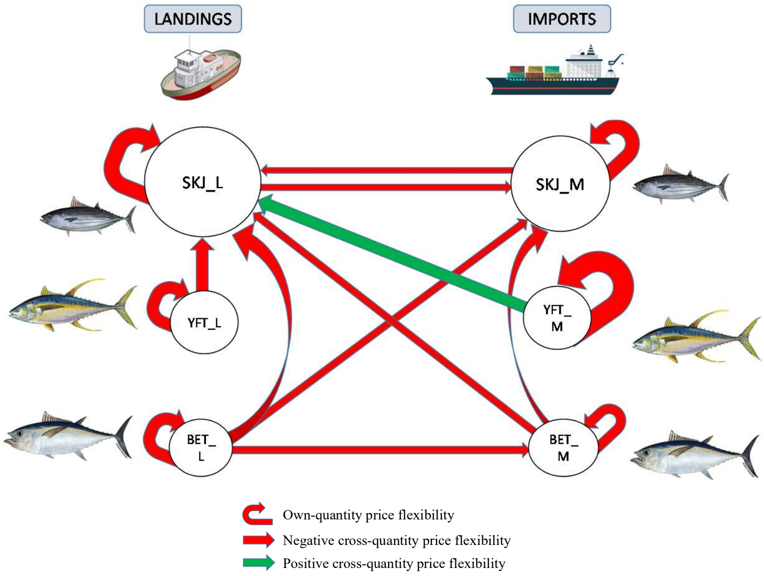

Fig. 7 Own quantity and cross-quantity flexibilities

(Arrows are proportional to the absolute values of flexibility coefficients. The direction of arrows indicates the influence of the quantity of one particular species onto prices of another (cross) or same (own) species. The color is for the sign (green=positive, red=negative). Only the absolute values greater than 0.20 were kept for this chart)

The uncompensated own-quantity price flexibility of yellowfin imports (-1.80) implies that revenues can increase/decrease proportionately more/less than yellowfin import quantities, suggesting possibilities for increased processing profits by reducing yellowfin imports and/or substituting local fish for them (depending upon processing costs) (Table 1 & Fig. 7). Yellowfin, whether imports or landings, is higher priced than cannery-grade skipjack or bigeye caught by purse seiners. Yellowfin, when canned (especially with olive oil) or processed into nuggets, burgers, or fillets, generally fills a premium place in the retail market. The elastic yellowfin imports own-quantity price flexibility, luxury status of yellowfin imports (from the scale flexibility), and unresponsiveness of yellowfin import prices to changes in quantities of yellowfin and bigeye landings and skipjack and bigeye imports (statistically insignificant uncompensated cross-quantity price flexibilities, Section 4.2.2.) support the notion that yellowfin import prices and demand are largely independently determined, contributing to a distinct export market segment (to EU) with insufficient domestic landing sourcing. The high own-quantity price flexibility indicates high responsiveness of the yellowfin import price to changes in its own supply. In sum, yellowfin imports may not fully and consistently conform with market forces, and instead serve to maintain Ecuadorian processing at high capacity, stable employment, and satisfy domestic and especially export market contracts to the European market (the final market for much of Ecuador's canned product).

4.2.2. Uncompensated (Marshallian) cross-quantity price flexibilities

Most uncompensated cross-quantity price flexibilities (Table 1 off-diagonal elements) are negative, and hence q-substitutes, with three notable exceptions of q-complementarity centered around yellowfin imports quantities and prices: (1) skipjack landings quantity-yellowfin imports price, (2) yellowfin imports quantity-skipjack landings price, and (3) yellowfin imports quantity-yellowfin landings price. Yellowfin imports clearly have a unique relationship with skipjack and yellowfin landings, reinforcing the conclusion that yellowfin imports form a distinct but interrelated market segment. No other landings or imports quantity has a statistically significant (at 5% or 1%) relationship with yellowfin imports price. Almost all other estimates for landings and imports quantities except for bigeye and yellowfin imports are statistically significant q-substitutes at 1% or 5%, and all are inflexible, reinforcing the conclusion that yellowfin imports form a distinct market segment. Hence, with an increase in quantity of Q_i, buyers for most of potential combinations other than those involving many of the yellowfin and bigeye import quantities and prices substitute away from the product leading to a fall in P_j. A marginal increase in Q_i mostly has a q-substitution effect on Q_j when all other quantities $Q_k, k \neq i, j$, are fixed, and P_i should be lower to induce buyers to purchase the same quantity of Q_i. For example, a 1% increase in yellowfin landings is associated with a 0.48% decrease in skipjack price. We now examine the four separate quarters of Table 1.

The uncompensated cross-quantity price flexibilities for skipjack, bigeye, and yellowfin landings quantities and their prices are all negative and statistically significant at 1% other than yellowfin landings quantity and bigeye landings price, indicating q-substitution, and price inflexibility (upper left-hand quarter of Table 1). The landings market is well integrated by price and there is some flexibility in substituting one species for another to keep processing lines operating, fill demand, and adapt to changing species supply. The substitution between skipjack landings and yellowfin landings can be satisfied partly through yellowfin sourced as either floating object bycatch or from unassociated sets (free schools of tunas). Purse-seine caught yellowfin is harvested as a primary species in unassociated sets (sometimes opportunistically) and larger in size than when setting on floating objects where it is generally smaller in size and younger. In these markets, large yellowfin caught on free schools receives a higher price than skipjack but floating-object caught fish have lower production costs when the reduced search time and probability of a successful set is considered.

The uncompensated cross-quantity price flexibilities for landings quantities and imports prices indicate inflexible, statistically significant at 1% q-substitution between skipjack, yellowfin, and bigeye landings quantities and skipjack and bigeye prices but q-complementarity between skipjack landings quantities and yellowfin import prices (upper right-hand quarter of Table 1).

Skipjack landings substitute for skipjack and bigeye imports, consistent with Manta as a "skipjack port" relying on floating object-caught fish (dominated by skipjack) and processor reliance on Manta landings with skipjack imports "filling in the demand gaps" as required. The q-complementarity between skipjack landings and yellowfin imports would indicate that an increase (decrease) in skipjack landings increases (decreases) the price a buyer is willing to pay for yellowfin import price (by a small amount), but it does not appear as statistically significant. However, the symmetric relationship between yellowfin imports and skipjack landing prices confirms a q-complementarity, showing a connection between the two products. Increased imports of yellowfin are probably not sufficient to meet the raw material requirements to maintain Ecuadorian processing at high capacity, stable employment, and satisfy domestic and export market contracts to the European market, thus creating pressure on the skipjack landing price too.

The uncompensated cross-quantity price flexibilities for skipjack and bigeye import quantities and skipjack and bigeye import prices are negative, statistically significant at 1% or 5%, inflexible, and q-substitutes indicating their integration into the skipjack-centered Manta market with yellowfin imports forming a distinct but connected market segment (lower right-hand quarter of Table 1). Substituting one skipjack and bigeye import for the other readily follows from the control of imports, i.e. buyers can easily choose which species to import and for which purpose. Buyers can choose among skipjack and bigeye to import to fill domestic and export market orders for the skipjack-centered market segment. The import market for skipjack and bigeye is integrated by price.

In sum, the Manta market is comprised of two distinct but connected segments, one centered around skipjack landings and imports with widespread q-substitution with bigeye and yellowfin landings and bigeye imports and the other segment centered around yellowfin imports quantities and prices which may concern a niche market. Skipjack landings (36% expenditure share) and yellowfin imports (14% expenditure share) link the two segments through q-complementarity between yellowfin import quantities and skipjack landing prices. The landings market is well integrated by prices, with inflexible q-substitution among all species. Landing quantities impact landings prices for skipjack, bigeye, and yellowfin. Import quantities of all species (but especially skipjack, Figures 4 and 5) fill domestic and export market demand gaps, and imports of skipjack and bigeye place downward pressure upon the landing prices of skipjack, bigeye and yellowfin and import prices of skipjack and bigeye.

4.2.3. Trends in landing prices

Uncompensated q-substitution between skipjack landings and imports, and bigeye imports with both skipjack landings and imports suggests that increased skipjack and/or bigeye imports would place downward pressure upon skipjack, bigeye, and yellowfin landings prices. While this downward pressure would be dampened by uncompensated q-complementarity between yellowfin imports and skipjack landings prices, the smaller volume of yellowfin imports (14.6% expenditure share) compared to combined skipjack and bigeye imports (30.6% expenditure share) gives a net downward pressure upon landing prices. The interests of vessel owners and crew do not align with those of processors, firms in the supply chain, and exporters, who all require imports to fill the demand gap, and the interests of domestic consumers who favor lower landing prices to the extent they are passed on to the shelf-stable domestic market.

4.2.4. Manta and Bangkok markets

The Manta and Bangkok markets display differences in uncompensated price responsiveness for many categories of skipjack and yellowfin products, where the Bangkok market is comprised solely of frozen imports (from transshipments) (Sun et al. 2017). All own- and cross-quantity prices for Bangkok skipjack and yellowfin imports are inflexible, negative and statistically significant, indicating strong q-substitutability between skipjack and yellowfin: the price of frozen skipjack would be equally sensitive to its own import quantity and to the Thailandese imports of yellowfin (flexibility of -0.797 and -0.801, respectively; Sun et al. 2017). The Manta ex-vessel market is similar to the Bangkok market with inelastic uncompensated own-quantity price flexibilities for skipjack, both landings and imports.

The Manta market differs from the Bangkok market along two dimensions. First, the Manta market includes both vessel landings and imports, while the Bangkok market is largely comprised of frozen transshipments. Second, the Manta market is comprised of two distinct, albeit connected, segments. One segment of the Manta landings market centers around skipjack landings and imports, is well integrated by prices, and excludes yellowfin imports. The second (linked) segment centers around yellowfin imports but links to the landings market through skipjack and yellowfin landings prices. Beyond these differences of market supply, a cointegration analysis[2] showed that Bangkok and Manta are very well integrated for both yellowfin and skipjack species, even when the two species are analyzed altogether. Moreover, prices changes are spatially transmitted in both directions. In other words, none of the Thailandese or Ecuadorian markets dominates the other in terms of price leadership.

4.3. Economic Welfare

Table 3 shows the decline in economic welfare throughout the value chain from the ex-vessel market through the consumer retail market in Ecuador for a 5% decline in each product category as a necessary input. As expected in absolute terms, $QEV_i > QCS_i > QCV_i$[3]. The estimated welfare declines for product i incorporates adjustments in the consumption of all product forms (since the inverse demand functions are equilibrium functions given a separability assumption).

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[2] This analysis (VAR models, multivariate cointegration, law of one price, Granger causality …) was left in the supplementary materials to avoid tedious presentation.

[3] Quantity-based equivalent variation (QEV), quantity-based consumer surplus variation (QCS), quantity-based compensating variation (QCV). Because the consumer is worse off after the quantity reduction (i.e. we saw from the IAIDS model that the Manta prices over-reacted to a decreasing quantity, therefore the consumer has to spend more to maintain the same level of utility), the variations represent the willingness to pay (accept) to restore their initial (QCV) or final (QEV) utility level. What is desirable for vessel owners might not be so for local and foreign consumers.

The closeness of all three welfare measures indicate that the scale effect on economic welfare is comparatively limited.

Table 3. Economic welfare effects (loss) of 5% decline in quantity (US$2020)

PRODUCT CATEGORY	EQUIVALENT VARIATION	CONSUMER SURPLUS	COMPENSATING VARIATION
SKIPJACK LANDING	1,292,548	1,272,352	1,252,156
BIGEYE LANDING	298,247	297,268	296,290
YELLOWFIN LANDING	320,467	319,513	318,560
SKIPJACK IMPORTS	963,431	956,667	949,903
BIGEYE IMPORTS	169,322	169,195	169,068
YELLOWFIN IMPORTS	552,128	540,597	529,066

Note: Calculated at arithmetic sample mean.

The salient result is the adverse welfare impact upon Ecuadorian society of declines in skipjack landings and imports, with declines in yellowfin imports also important (Table 3). Skipjack, whether landings or imports, is central to the Ecuadorian tuna industry (with an average of 61.9% of all expenditures, Table A2) and along with yellowfin landings are necessary goods. Yellowfin import quantities and expenditures (average 24.5%) are a luxury good, and a different (albeit interrelated) market segment that would be less impacted compared to skipjack. Bigeye, as expected due to its low landing and import quantities and expenditures (average 13.6%, Table A2), has the smallest impact. Bigeye catch is largely incidental when setting on floating objects, but it is a target species for longline vessels and a limited number of purse seine vessels making deeper sets on floating objects and their welfare would be adversely impacted.

5. Conclusions

The price flexibility of fish markets has been extensively studied through econometric studies in the fisheries economics literature (Barten and Bettendorf 1989, Eales et al. 1997, Asche et al. 2007, Gallet 2009). Overall, the direct demand for fish products was found rather inelastic (absolute value smaller than unity), hence rather price flexible because the reciprocals of price flexibilities provide lower bound on elasticities (Deaton 1979). The results concerning tuna are rather the opposite: elastic (inverse) demand to prices and scale flexibility close to or slightly below unity (Sun et al. 2017, Guillotreau et al. 2017). Moreover, previous studies about the delineation of tuna markets report strong market interconnections at the worldwide level: prices of skipjack, yellowfin and bigeye tunas fixed in the major market places around the world (Thailand, Japan, Ecuador, Spain, Mexico, American Samoa, Abidjan, Indonesia, etc.) move altogether in the long run and no regional price can deviate from their long-run relationship for too long (Squires et al. 2007, Jeon et al 2008, Jiménez-Toribio et al. 2010).

The consequences of such indicators, taken as economic incentives to increase or reduce the fishing effort, are important for fishery managers. When local fisheries are integrated into global markets, they are more likely to become unsustainable if not regulated within a multi-level institutional framework (Crona et al. 2015, Fryxhell et al. 2017). The income derived from fishing can be improved at low level of effort in a local fishery because of the incentives offered by the price flexibility of the local market (Elsler et al. 2019). Compared to other oceans, the East Pacific Ocean fisheries exhibit rather healthy tropical tuna stocks and sustainable effort level regarding skipjack and yellowfin, the two major species, but bigeye tuna raises more concerns according to IATTC (2021). This is why it seems so important to understand the economic incentives of vessel owners to accept management measures such as closure days which can reduce their tuna catches.

The present study examines the integration of the Manta market to the global one through the responsiveness of regional prices to changes in domestic landings and imports, and to price changes in Bangkok, acknowledged as market leader (Jiménez-Toribio et al. 2010, Guillotreau et al. 2017, Sun et al. 2017). The Manta market, dominated by skipjack landings and imports, is on the whole well integrated by prices with two distinct but interconnected market segments. The first centers around the mutually substitutable imports and landings. Skipjack, yellowfin, and bigeye landings on the one hand, and skipjack and bigeye imports on the other, readily substitute for each other in a market well integrated by price. The second segment centers around yellowfin imports, which are linked to the first segment through quantities of skipjack landings and yellowfin imports and their impacts upon the prices of skipjack and yellowfin landings prices and yellowfin import prices. Imports are important to keep processing capacity utilization and employment high and fill domestic and growing export demand. Manta makes no exception: the important processing capacity of 500,000 mt (and resulting employment) is supplied almost in equal shares by both sources.

The empirical results answer the six questions. First, on the basis of scale flexibilities, we found evidence of economic incentives to simultaneously reduce the regional landings of skipjack, bigeye and yellowfin, since higher prices would more than compensate for lower catches, and revenues would increase other things being equal. Second, if vessel owners face incentives to reduce catch, processors and end consumers would have to spend more for their fish, unless they can readily substitute imports for reduced landings. Consequently, the economic welfare of the supply chain firms (processors, exporters) and consumers would decline with reduced landings and imports. For the sole demand of skipjack, the main species of the Manta market, buyers would need to pay an extra amount of 1.3 MUSD for landings and nearly 1 MUSD more to achieve the same level of utility with a 5% reduction of both landings and imports, respectively.

Third, increasing imports of skipjack and to a lesser extent bigeye to meet the processing industry’s raw material requirements potentially depress ex-vessel prices, even though the price response seems to be of lower magnitude for bigeye and yellowfin than skipjack. The interests of vessel owners, skipper, and crew and firms supporting vessels do not align with those of processors, firms in the supply chain, and exporters, who all require imports to fill the demand gap and who, along with consumers, naturally prefer lower prices. In contrast, yellowfin imports increase skipjack and yellowfin landings prices in order to maintain processing capacity and employment and satisfy domestic and export demand. Fourth, skipjack landings and imports dominate the Manta market and the two supply sources substitute for each other, as shown by the uncompensated cross-quantity flexibilities of Table 1. These findings are consistent with Manta as a “skipjack port” relying on floating object-caught fish (dominated by skipjack) and processors’ reliance on Manta landings with skipjack imports filling the export demand gap.

Fifth, the Manta and Bangkok markets differ in that Manta has both landings and imports of comparable amounts, thus many more substitution opportunities combining species and origins than Bangkok which relies only on frozen transshipments (imports). They also differ in that the Manta market demonstrates two distinct but interrelated segments, one centered upon skipjack and the other upon yellowfin imports. However, Bangkok occupies a better location between the fishing waters of the West and Central Pacific, and the Indian Ocean fisheries. Both marketplaces are fundamentally skipjack and export oriented (domestic demand cannot possibly absorb the supply). Skipjack and yellowfin tuna prices respond to their own import quantity in the two ports, but Manta prices are more flexible to quantity changes (scale flexibilities between -1 and -1.237 for the landings of the three main species and skipjack imports) than Bangkok prices to imports (scale flexibilities of -0.995 and -1.021 for skipjack and yellowfin tuna, respectively; Sun et al. 2017). Such a trend shows the growing influence of Ecuador, supplied by the EPO fishery but exporting to EU countries a great proportion (60%) of its sales of tuna products (Ministerio de Comercio Exterior 2017), thus explaining the peculiar market position of yellowfin imports. Manta captures the market information released by Bangkok to set up its own ex-vessel and import prices, but the reciprocal influence is also true for Bangkok using the price level signals of the Ecuadorian port. The elasticity of price transmission shows nonetheless that Manta prices respond to a greater extent to Bangkok changes than the latter respond to Manta’s fluctuations.

The Manta market and vessel catching sector must be viewed as one part, along with imports, of a source of employment and value added in the broader Ecuadorian tuna economy that includes the entire value chain through the export market. A major difference from the Bangkok market is the contribution of a catching sector to the processing sector, export market, and broader economy.

Sixth, modest seasonality in landings expenditures varies by species. Skipjack landings, which dominates landing volume, have highest expenditures and prices in the first quarter. Vessels that could fish freely throughout the Management Year under a transferable day credit scheme would face modest incentives to increase their first quarter landings.

To summarize the main outcomes, we provided evidence of the increasing importance of the Manta fishing port on the global tuna market, analyzed the link with the Bangkok market, showed that degrees of freedom for catch and import reduction do exist for the EPO managers since the vessel owners’ income is likely to be increased, and showed the importance of imports, processing, employment, and value added through the entire value chain up to exports for the broader Ecuadorian economy. The overall welfare economic effects of more stringent regulation measures should nonetheless be fully considered because processors, traders and end consumers would be significantly and adversely affected if any decrease of regional landings would not be offset by an equivalent amount of imports, in particular of skipjack products. This research represents a new and original contribution to the knowledge of tuna markets operating with a multi-level structure which affects distinctly the fishing industry, multinational processing and trading companies, and small-scale fishers who have no access to export markets (Elsler et al. 2019). A possible extension of this research could scrutinize the role of trade policies or conflicts hampering the global trade of tuna products (Campling 2016) and the impact trade restrictions may have on the extent of market integration.

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Supplementary Materials

A1. Other indicators of complementarity-substitutability and economic welfare

A1.1 Morishima Elasticity of Complementarity

The Morishima Elasticity of Complementarity between commodities i and j, MEC_{ij}, is a nonsymmetric two-quantity, one-price flexibility that shows how the price ratio i/j changes due to a 1% increase in Q_i holding the quantities of all other commodities constant (Blackorby and Russell 1989, Kim 1997).

$$MEC_{ij} = f_{ji}^{c} - f_{ii}^{c}. \tag{A1}$$

$MEC_{ij} < 0$ indicates q-substitutes and $MEC_{ij} > 0$ indicates q-complements. The MEC is asymmetric, i.e. $MEC_{ij} \neq MEC_{ji}, i \neq j$.

Empirical results.

MECs in Table 3 are understood as follows. The first row/third column value of 0.20843, for example, reports that a 1% increase in the quantity of skipjack landings purchased in the Manta ex-vessel market results in a 0.21 % increase in the ratio of skipjack landed demand price to the bigeye landed demand price, all other quantities and utility held constant.

The MEC are almost all statistically significant at 1% with some at 5% and one at 1% (Table A1.1). Almost all MECs are positive for skipjack, bigeye, and yellowfin landings and skipjack imports, indicating pervasive q-complementarity. All q-complementary $\left|MEC_{ij} < 1\right|$, i.e. their absolute values are less than one, indicating that a 1% increase in Q_i increases the price ratio i/j by less than 1%. The dominance of q-complementary MECs with inverse demand can be attributed to the value of the own-price flexibility is larger in absolute value than the cross-price flexibilities. The single exception is the price-flexible q-substitution between yellowfin landings and skipjack imports. Thus, a 1% increase in the quantity of yellowfin landings decreases the price ratio between yellowfin landings and skipjack imports by more than 1%. Buyers exert more control over skipjack imports (since they can readily import from the world market) and the skipjack imports fill a different market niche than other products, reinforcing the conclusion that skipjack imports are residual fillers of the derived demand gap when landings are insufficient for processing capacity and export demand.

Almost all MEC values are inelastic, indicating that inverse demand price ratios change proportionately less than the change in one of the quantities due to high substitution between species-product forms. Relative prices (price ratios) between these two species-product forms are comparatively stable with changes in the supply of one of the products. The market is highly integrated and highly substitutable between these products. Price and quantities of these products (with small positive MECs) absorb small shocks due to sudden changes in price, smooth out market responses, and stabilize consumer welfare.

Table A1.1. Morishima Elasticities of Complementarity

	Skipjack Landing	Bigeye Landing	Yellowfin Landing	Skipjack Imports	Bigeye Imports	Yellowfin Imports
Skipjack Landing		0.1937*** (0.0561)	0.2121*** (0.0642)	0.1997*** (0.0391)	0.4290*** (0.0225)	0.3069*** (0.0226)
Bigeye Landing	0.2544*** (0.0830)		0.1772* (0.1060	0.197^{1**} (0.0813)	0.2225** (0.0941)	0.2199** (0.0815)
Yellowfin Landing	0.190^{4***} (0.0611)	0.158^{3**} (0.0699)		-1.6055*** (0.0525)	0.1872*** (0.0872)	0.1639*** (0.0498)
Skipjack Imports	0.0822** (0.0407)	0.1778*** (0.0480)	0.2153*** (0.0409		0.1515** (0.0739)	0.1692*** (0.0256)
Bigeye Imports	0.1619** (0.0559)	0.1749** (0.0721)	0.1634** (0.0717)	0.1554** (0.0643)		0.1578** (0.0570)
Yellowfin Imports	0.9310*** (0.0154)	0.9724*** (0.0213)	0.9090*** (0.0217)	0.9423*** (0.0175)	0.9264*** (0.0208)	

Note: Linearized standard errors in parentheses. MECs are calculated at sample mean.
*** for 1% level of significance, ** for 5%, * for 10%.

A1.2. Allais Coefficient and Intensity of Interaction

The Allais coefficient evaluates the relationship between two different commodities using a transformation of the Antonelli matrix H (second-order parameters of the inverse demand system) (Barten and Bettendorf 1989). The Allais notion of complementarity, substitution and independence is invariant under monotone increasing transformations of the utility function. Denote the vectors $\Gamma = \gamma_i$ and $w = w_i$ and γ_{ij} as the ij^{th} element of the Antonelli matrix, Γ. By selecting r and s as the reference pair of goods, the Allais coefficient for commodity pair i, j relative to reference pair r, s with the inverse demand system can be defined as:

$$A_{ij} = \frac{\gamma_{ij}}{w_i w_j} - \frac{\gamma_{rs}}{w_r w_s} + \left[\frac{\gamma_i}{w_i} - \frac{\gamma_r}{w_r}\right] + \left[\frac{\gamma_j}{w_j} - \frac{\gamma_s}{w_s}\right]. \qquad \text{(A2)}$$

A_{ij} is free of units of measurement, but changes with the commodity pair r, s chosen as the standard of comparison. A_{ij} compares the relative strength of the complementarity and substitutability between the commodity pair i and j compared to the reference pair of goods r and s. The above equation indicates that $A_{ij} = 0$. $A_{ij} > 0$ indicates that i and j are stronger complements than r and s, while $A_{ij} < 0$ indicates that i and j are stronger substitutes than r and s, and $A_{ij} = 0$ means that i, j has the same type of interaction as the reference commodity pair, r, s. Nonetheless, the order of magnitude of the A_{ij} can differ considerably from pair to pair or from the corresponding A_{ii} and A_{jj}.

The measure of intensity of interaction based on the Allais coefficient can be defined as (Barten and Bettendorf 1989):

$$\theta_{ij} = \frac{A_{ij}}{\left[A_{ii} A_{jj}\right]^{\frac{1}{2}}}, \qquad \text{(A3)}$$

which for a negative definite matrix is $A = \left[A_{ij}\right], \theta_{ij}$, and varies between –1 (perfect substitution) and +1 (perfect complementarity), i.e. $-1 \leq \theta_{ij} \leq 1$. $\theta_{ij} > 0$ indicates that i and j are more complementary than r and s, while $\theta_{ij} < 0$ indicates that i and j are stronger substitutes than r and s. $\theta_{ij} = 0$ means that commodity pair i and j has the same interaction as r and s. By construction $\theta_{ii} = 1$, since a commodity i is its own perfect substitute. The Allais intensities θ_{ij} are more easily compared across commodities than the Allais coefficients A_{ij} since they are normalized.

Empirical results

The Allais Intensity coefficients are uniformly positive for the relationships across different commodities, i.e. for the off-diagonal elements, except for negative skipjack imports-yellowfin imports (Table A1.2). The Allais intensity coefficients γ_{ij} > (<) 0 indicate that i and j are more complementary (substituted) than reference pair r, s, here skipjack landings – skipjack imports (the two most important commodities by volume and expenditure). The dominant $\gamma_{ij} > 0$ indicate these commodity pairs are more complementary in consumption than the reference pair skipjack landings–skipjack imports. Compared to skipjack landings-skipjack imports, an increase in the quantity of one of the other species increases the price of another non-skipjack species. This conclusion reinforces the centrality of skipjack to the Manta market and the substitution between imports and landings of what are largely fungible commodities. The sole negative Allais intensity coefficient for skipjack imports-yellowfin imports indicates a more substitute relationship than the reference pair skipjack landings-skipjack imports (suggesting import volumes per se are relatively more important than either species in isolation). Compared to skipjack landings–skipjack imports, an increase in the quantity of yellowfin imports increases its price. Product relationships with yellowfin imports are the strongest relationships and mostly complementary in consumption, reflecting yellowfin imports as a separate market segment.

Table A1.2. Allais Intensity Coefficients

	Skipjack Landing	Bigeye Landing	Yellowfin Landing	Skipjack Imports	Bigeye Imports	Yellowfin Imports
Skipjack Landing	-1.00000	0.16759	0.073291	N/A	0.20439	2.03370
Bigeye Landing		-1.00000	0.12544	0.20946	0.18083	0.68597
Yellowfin Landing			-1.00000	0.17246	0.15487	1.09192
Skipjack Imports				-1.00000	0.17035	-0.88189
Bigeye Imports					-1.00000	0.60317
Yellowfin Imports						-1.00000

Note: $-1\ (perfect\ substitutes) \leq\ \gamma_{ij}\ \leq 1\ (perfect\ complements)$. Skipjack landing-Skipjack imports are reference pair and without Allais intensity coefficient value.

A1.3. Economic Welfare

The economic welfare impacts of a reduction in total quantity landed or imported can be evaluated by calculating quantity-based compensating (QCV) and equivalent (QEV) variations, which are measured as areas below inverse Hicksian compensated demand curves (Kim 1997). (QCV is the additional normalized expenditure required for the consumer to be restored to the initial utility level U^0 when facing the bundle of quantities $\boldsymbol{Q}^1$ and QEV is the additional normalized expenditure required for the consumer to achieve final utility level U^1 when facing the bundle of quantities $\boldsymbol{Q}^0$.) To the extent that the inverse demand curves are equilibrium demand curves, the economic welfare measure captures both consumer and producer surplus of harvesters and firms in the supply chain (Just et al. 2004).

The estimated compensated own-price flexibilities from (5) are used to calculate QCV and QEV. Consumer surplus is evaluated from Marshallian uncompensated inverse derived demand curves. The Hicksian and Marshallian measures differ by the proportional change in all quantities, the scale effect.

The reduction in bigeye imports generates a movement along the inverse derived demand for landed bigeye and a corresponding change in consumer value and producer surplus to fish processors. Prices of all related species in derived demand change in equilibrium due to substitution in demand, and because bigeye is a necessary input to consumers and processors and the inverse demand system captures all relevant species substitutes, the demand system is an equilibrium demand system for this necessary input, and consequently captures all changes in consumer and producer (processor) welfare (Just et al. 2004).

Because the inverse demand curve is not derived from a closed form expenditure or distance function, computing QEV requires use of the uncompensated inverse demand curve to compute prices for the final set of quantities. The new demand price induced by the hypothetical reduction in quantity for product i for both uncompensated and compensated demand can be represented as (Kim 1997, Park et al. 2004):

$$P_i^1 = P_i^0 + \Delta P_i = P_i^0 \left[1 - f_{ii} \frac{\Delta Q_i}{Q_i}\right], \qquad \text{(A4)}$$

where $\Delta P_i = P_i^1 - P_i^0$ is the change in price and $\Delta Q_i = Q_i^1 - Q_i^0$ is the change in quantity i.

The exact welfare measures for a change in quantities $\boldsymbol{Q}^0$ to $\boldsymbol{Q}^1$ are written (Kim 1997): $QCV = \int_{Q_i^0}^{Q_i^1} \sum_i ID_i^c(U^0, \boldsymbol{Q}) dQ_i$ and $QEV = \int_{Q_i^0}^{Q_i^1} \sum_i ID_i(U^1, \boldsymbol{Q}) dQ_i$. When $\boldsymbol{Q}^1 < (>)\, \boldsymbol{Q}^0$, QCV measures willingness to pay (accept). The consumer is worse (better) off when facing quantities $\boldsymbol{Q}^1$ compared to $\boldsymbol{Q}^0$ if $QCV > (<)$ 0. When $\boldsymbol{Q}^1 < (>)\, \boldsymbol{Q}^0$, QEV measures willingness to accept (pay). As with QCV, the consumer is worse (better) off when facing quantities $\boldsymbol{Q}^1$ compared to $\boldsymbol{Q}^0$ if $QEV > (<)$ 0. QEV is smaller (larger) than QCV for an increase (decrease) in the quantity of one good.

From a Hicksian compensated inverse demand assumed linear and a change in quantity from Q_i^0 to Q_0^1, the approximate QCV is (Kim 1997, Park et al. 2004):

$$QCV_i = (-\Delta Q_i)\left\{P_i^0 + 0.5\left[f_{ii}^c \frac{P_i^0}{Q_i^0}\right] \Delta Q_i\right\}, \qquad \text{(A5)}$$

and the approximate QEV is (Kim 1997, Park et al. 2004):

$$QEV_i = (-\Delta Q_i)\left\{P_i^1 - 0.5\left[f_{ii}^c \frac{P_i^0}{Q_i^0}\right] \Delta Q_i\right\}. \qquad \text{(A6)}$$

Computing QEV requires use of the uncompensated demand curve to compute prices at the final set of quantities (Lee and Thunberg 2013). The uncompensated quantity flexibilities are used to construct P_i^0 for the QEV measure. This implies that the QEV measure depends on the path taken along the uncompensated demand curves.

Marshallian consumer surplus is expressed in terms of uncompensated inverse demand curves. The exact welfare measures for a change in quantities $\boldsymbol{Q}^0$ to $\boldsymbol{Q}^1$ is (Kim 1997): $QCS = \int_{Q_i^0}^{Q_i^1} \sum_i ID_i^U(\boldsymbol{Q})dQ_i$, which is the area below the Marshallian uncompensated inverse demand curve ID_i^U. When the scale effect is zero ($f_i = 0$), $QMS = QCV = QEV$. For an increase in a normal good, $QEV < QCS < QCV$ (since the uncompensated inverse demand curve is steeper than the compensated inverse demand curve). With the assumption of linear Marshallian uncompensated inverse demand, the approximate quantity-based measure of consumer surplus is calculated as:

$$QCS_i = (-\Delta Q_i)\left\{P_i^0 + 0.5\left[f_{ii}\frac{P_i^0}{Q_i^0}\right]\Delta Q_i\right\} . \tag{A7}$$

For a normal good, the uncompensated inverse demand curve is steeper than that of the compensated curve. Hence, uncompensated price responds more than compensated price for any given quantity change, as indicated by a larger absolute value of the uncompensated than compensated own price flexibility, i.e. the slope is larger. This implies that the QCS associated with a change in quantities from to is bounded from below by the QCV and from above by the QEV.

All calculations are performed with $\Delta Q_i < 0$, i.e. preceded by a negative sign.

A2. Summary Statistics of the Data

Table A2. Summary Statistics of the Manta, Ecuador Tuna Market

	Mean	Standard Deviation	Minimum	Maximum
Quantity (metric tons)				
Skipjack Landed	16,246	5,676	4,567	29,174
Bigeye Landed	3,224	1,301	327	6,671
Yellowfin Landed	3,703	1,343	420	7,847
Skipjack Imports	7,119	3,340	1,794	16,516
Bigeye Imports	1,036	544	217	3,397
Yellowfin Imports	2,585	1,067	899	6,219
Expenditure (Revenue) (US$2020)				
Skipjack Landed	24,858,800	9,603,244	8,066,290	48,869,100
Bigeye Landed	5,849,805	2,777,898	665,744	13,559.000
Yellowfin Landed	6,626,351	2,505,665	984,355	11,985,800
Skipjack Imports	18,095,000	8,692,259	4,248,150	45,632,000
Bigeye Imports	3,403,117	1,814,541	649,765	10,449,600
Yellowfin Imports	9,752,333	4,404,996	2,610,807	28,339,000

Price (US$2019/metric ton)				
Skipjack Landed	1,589.98	434.67	745.25	2,493.30
Bigeye Landed	1,807.92	484.24	922.45	2,779.41
Yellowfin Landed	1,851.48	414.89	924.48	2,932.71
Skipjack Imports	1,536.41	391.95	912.21	2,440.74
Bigeye Imports	1,799.42	415.52	1,162.20	3,088.47
Yellowfin Imports	2,077.70	377.15	1,226.41	3,078.44
Expenditure (Revenue) Share (%)				
Skipjack Landed	36.29	9.06	11.13	56.32
Bigeye Landed	8.67	3.34	0.83	16.16
Yellowfin Landed	9.94	3.33	1.25	19.38
Skipjack Imports	25.62	7.66	8.14	42.23
Bigeye Imports	4.93	2.05	1.10	11.01
Yellowfin Imports	14.55	5.53	3.95	3.53

Note: Linear aggregation of imports under consumption and MR21 regimes. 93 observations.

A3. Estimation of the IAIDS model

A3.1. Preliminary Analysis

Prior to estimation of the system of inverse demand equations, tests for the properties of the time series of the data were conducted. The statistical properties of most estimators in time series rely on the data being (weakly) stationary. Loosely speaking, a weakly stationary process is characterized by a time-invariant mean, variance, and autocovariance. Phillips-Perron test statistics (1988) can be viewed as Dickey–Fuller statistics that have been made robust to serial correlation by using the Newey–West (1987) heteroskedasticity- and autocorrelation-consistent covariance matrix estimator. Augmented Dickey-Fuller (1981) tests also rejected the null hypothesis of a unit root (indicating stationarity) when trend was excluded (it was not statistically significant) and lag lengths were limited (but additional lags were individually statistically insignificant).

Phillips-Perron (1988) tests for unit roots of the expenditure shares w_i and the logged quantities $ln(Q_i)$ for all product categories reject at 1% the null hypothesis of a unit root for each product category (i.e. the null hypothesis that each product category's time series is integrated order one). The tests were performed without a time trend and with a time trend (which was not statistically significant except for yellowfin and bigeye imports' quantities and revenue share) and a Newey-West (1987) lagged variable of 1, 3, and 7 periods. Rejection of the unit root null hypothesis indicates that the data are stationary (integrated of order 0, I(0), and that transformation of the data (e.g. by first differencing) is not necessary. These results support the figures above.

First-order serial correlation was first evaluated by Durbin-Watson (DW) statistics from: (1) Eicker (1967)-Huber (1967)-White (1980) heteroscedastic-consistent ordinary least squares (OLS) equation-by-equation estimation for each expenditure share equation (91 observations for each equation) and (2) the maximum likelihood estimates of all equations (with quarterly dummy variables) reported for each equation (91 observations for each of 6 estimated equations, 57 unique parameters in total, 546 observations for the system, and a total of 546-57 = 489 of freedom for the entire system). The DW statistics are as follow for each equation with the maximum likelihood estimated statistics in parentheses: (1) skipjack catch 1.74 (1.65), (2) bigeye catch 1.97 (2.00), (3) yellowfin catch 1.54 (1.39), (4) skipjack imports 1.96 (1.80), (5) bigeye imports 1.90 (1.86), and (6), yellowfin imports 1.27 (this equation is dropped for maximum likelihood estimation). For 90 observations, DW indeterminate range lower bound is 1.288 and upper bound is 1.769. The estimated DW statistics exceed the indeterminate upper range for bigeye catch, skipjack imports, and bigeye imports, indicating absence of positive first-order serial correlation. A second equation-by-equation test of first-order serial correlation (Wooldridge 2002) regressed, by ordinary least squares with heteroscedastic-consistent standard errors, the residual from each OLS-estimated equation upon its own value lagged one period with robust standard errors (88 observations). At a 0.01 level of significance, the t-statistics were not statistically significant for any of the equations, although at 0.05 the yellowfin catch equation lagged residual was statistically significant.

First-order serial correlation was subsequently evaluated for the entire system of expenditure share equations by specifying a first-order serial correlation coefficient ρ constant across all equations, specifying the system of expenditure share equations (without the yellowfin import equation), estimating the system of equations by maximum likelihood allowing for an unknown form of heteroscedasticity in the standard errors, and conducting a Wald test for the null hypothesis (85 observations): $H_0: \rho = 0$. The result in this case was conclusive at the 0.05 and 0.01 levels of significance, not rejecting $H_0: \rho = 0$ with $\hat{\rho} = -0.133558\mathrm{E}-02, S.E. = 0.206124\mathrm{E}-02, t - ratio = -0.647951$, $p = 0.517$. Since the standard Berndt-Savin (1975) approach to correcting first-order serial correlation in a system of equations specifies a common value for the first-order serial correlation coefficient ρ to preserve the adding up restriction, the system-wide rejection of a system-wide common value for ρ, $H_0: \rho = 0$, was adopted. That is, the maximum likelihood estimates do not have a first-order serial correlation correction.

Potential endogeneity of the quantity regressors was evaluated by a Durbin (1954)-Wu (1973)-Hausman (1978) test. Following Wooldridge (2002), each of the six potentially endogenous quantity variables was regressed on exogenous variables and the resulting residuals from each of the six auxiliary regression equations specified as an additional regressor in each expenditure share equation, giving a Durbin-Wu-Hausman augmented regression test. Specifically, each quantity variable was regressed upon the following exogenous variables lagged one time period (sourced from the U.S. Saint Louis Federal Reserve Bank): real price of Brent oil and the producer price index of hot rolled steel sheet and strip, including tin mill products (accounts for the cost of cans in this derived demand curve). Additional regressors in the auxiliary regressions were Bangkok import market real prices of frozen whole skipjack, bigeye, yellowfin, and albacore tunas. Bangkok was found to be the primary location of global tuna price determination, but Ecuador was also found to influence (Jeon et al. 2008, Jiménez-Toribio et al. 2010). Hence, all prices were lagged one time period so that they are predetermined. Additional regressors in the auxiliary regressions were the constant, three quarterly dummy variables, and a monthly time trend to account for changes in biomass (estimates were unavailable). Alternative auxiliary regressions replaced Brent oil and tin prices with a multivariate ENSO index version 2 from NOAA and the US-EURO exchange rate and producer price index for No. 2 diesel fuel (the latter two both sourced from the U.S. Saint Louis Federal Reserve Bank). The residuals were included in each expenditure share equation as additional regressors (giving six additional regressors for each expenditure share equation) and the five-equation system of expenditure share equations (dropping the yellowfin import equation) was estimated by maximum likelihood. The log likelihood test statistic of the null hypothesis of exogenous quantity variable regressors, distributed chi-square with 30 degrees of freedom (one for each of the six residual parameters in each of the five estimated expenditure share equations) for this regression with and without the residuals and using real price of Brent oil and the producer price index of hot rolled steel sheet and strip as exogenous variables was $\chi^2_{df=30} = 7.94, p = 0.9999$, which is well below the critical value of 11.1 and 15.1 for the 0.05 and 0.01 levels of significance. When using the ENSO index, US-EU exchange rate, and producer price index for no. 2 diesel fuel, $\chi^2_{df=30} = 6.60, p = 0.9999$. The null hypothesis that the quantity regressors were exogenous was not rejected by either of the Durbin-Wu-Hausman augmented regression tests. If the quantity regressors were found to be endogenous, estimated parameters would be biased and inconsistent, and instrumental variable estimation through three-stage least squares or generalized method of moments would be required.

Monthly multivariate ENSO index version 2 from NOAA
https://psl.noaa.gov/enso/mei/
U.S. Dollars to Euro Spot Exchange Rate, U.S. Dollars to One Euro, Monthly, Not Seasonally Adjusted

A3.2. Inverse AIDS Model Estimation

The system of expenditure share equations was estimated by maximum likelihood, while dropping the yellowfin import expenditure share equation to avoid singularity of the covariance matrix. Parameter estimates with heteroscedastic-consistent standard errors are reported in Table A3.2. Parameter estimates of the yellowfin import expenditure share equation are estimated from the linear homogeneity and symmetry parameter restrictions, with linearized standard errors. The Wald test of null hypothesis that all yellowfin import parameter estimates are jointly zero is rejected at the one percent level of significance: $\chi^2_{df=11} = 432{,}756.56\ , p = value = 0.0000$. The second-order parameters γ_{ij} for squared and cross-product variables form the Antonelli matrix. A Likelihood Ratio test at 1% level of significance rejected the null hypothesis that the quarterly dummy variables are collectively zero: $\chi^2_{df=15} = 32.18$ (p=0.006084).

Table A3.1 Estimated Parameters of the System of Inverse Demand Equations

	Parameter Estimate	Standard Deviation	t-Ratio	p-Value
Skipjack Landings Equation				

Intercept	.191711	.066727	2.87305	0.004
Dummy Second Quarter	-.017521	.732440E-02	-2.39216	0.017
Dummy Third Quarter	-.992595E-02	.711240E-02	-1.39558	0.163
Dummy Fourth Quarter	-.910264E-02	.702000E-02	-1.29667	0.000
Skipjack Landing	.186514	.705220E-02	26.4477	0.000
Bigeye Landing	-.025345	.366251E-02	-6.91998	0.000
Yellowfin Landing	-.027253	.350618E-02	-7.77279	0.000
Skipjack Imports	-.073370	.567887E-02	-12.9198	0.000
Bigeye Imports	-.01463	.250936E-02	-5.83272	0.000
Yellowfin Imports	.038967	.014954	2.60579	0.000
Aggregate Quantity Index	-.085882	.012350	-6.95394	0.000
Bigeye Landings Equation				
Intercept	.165551	.034270	4.83081	0.000
Dummy Second Quarter	.012900	.415638E-02	3.10371	0.002
Dummy Third Quarter	.473082E-02	.381805E-02	1.23907	0.215
Dummy Fourth Quarter	.615124E-02	.374507E-02	1.64249	0.100
Bigeye Landing	.063219	.368367E-02	17.1620	0.000
Yellowfin Landing	-.928912E-02	.265885E-02	-3.49366	0.000
Skipjack Imports	-.018833	.308469E-02	-6.10542	0.000
Bigeye Imports	-.237180E-02	.194676E-02	-1.21833	0.223
Yellowfin Imports	-.776721E-02	.785181E-02	-.989225	0.323
Aggregate Quantity Index	-.326212E-02	.658273E-02	-.495557	0.620
Yellowfin Landings Equation				
Intercept	.142940	.033316	4.29047	0.000
Dummy Second Quarter	-.469317E-02	.387543E-02	-1.21101	0.226
Dummy Third Quarter	-.112837E-02	.375791E-02	-.300266	0.764

Dummy Fourth Quarter	-.995120E-02	.362082E-02	-2.74833	0.006
Yellowfin Landing	.073050	.330823E-02	22.0814	0.000
Skipjack Imports	-.017881	.296672E-02	-6.02723	0.000
Bigeye Imports	-.385923E-02	.190174E-02	-2.02931	0.042
Yellowfin Imports	.614975E-02	.768697E-02	.800022	0.424
Aggregate Quantity Index	-.018511	.641005E-02	-2.88787	0.004
Skipjack Imports				
Intercept	.272382	.072435	3.76035	0.000
Dummy Second Quarter	.302447E-02	.843746E-02	.358457	0.720
Dummy Third Quarter	.181318E-02	.797070E-02	.227481	0.820
Dummy Fourth Quarter	.983050E-02	.792275E-02	1.24079	0.215
Skipjack Imports	.154953	.668219E-02	23.1889	0.000
Bigeye Imports	-.012011	.237734E-02	-5.05220	0.000
Yellowfin Imports	-.024338	.017158	-1.41846	0.156
Aggregate Quantity Index	-.012231	.014266	-.857298	0.391
Bigeye Imports				
Intercept	.107039	.023418	4.57084	0.000
Dummy Second Quarter	.631580E-02	.266773E-02	2.36748	0.009
Dummy Third Quarter	.376915E-02	.256096E-02	1.47177	0.135
Dummy Fourth Quarter	.377475E-02	.248450E-02	1.51932	0.129
Bigeye Imports	.039345	.204262E-02	19.2619	0.000
Yellowfin Imports	-.464248E-02	.526585E-02	-.881621	0.343
Aggregate Quantity Index	.323212E-03	.438125E-02	.073772	0.945
Yellowfin Imports				
Intercept	.120377	.011771	10.2264	0.000
Dummy Second Quarter	-.045911	.124382E-02	-36.9109	0.000

Dummy Third Quarter	-.738049E-02	.159156E-02	-4.63727	0.000
Dummy Fourth Quarter	-.014768	.105415E-02	-14.0095	0.000
Skipjack Landing	-.032858	.906659E-03	-36.2405	0.000
Bigeye Landing	-.646664E-02	.615538E-03	-10.5057	0.000
Yellowfin Landing	-.836946E-02	.224702E-02	-3.72469	0.000
Skipjack Imports	.119563	.176393E-02	67.7823	0.000
Bigeye Imports	-.261462E-04	.104120E-02	-.025111	0.980
Yellowfin Imports	.741173E-03	.103756E-02	.714340	0.475
Aggregate Quantity Index	-.702651E-03	.101026E-02	-.695512	0.487

Maximum likelihood estimation with symmetry and linear homogeneity in quantities imposed. Heteroscedastic-consistent standard errors. Yellowfin imports parameters estimated from symmetry and linear homogeneity restrictions with linearized standard errors. $\chi^2_{fd=11} = 241325.69, p = 0.000$ that yellowfin import parameters and the three quarterly dummy variables in the yellowfin import equation are jointly zero.
Number of observations = 91. Log-likelihood = 1508.27. Schwarz B.I.C. = -1370.56.
Skipjack landing equation $R^2 = 0.938$, bigeye landing equation $R^2 = 0.874$, yellowfin landing equation $R^2 = 0.879$, skipjack import equation $R^2 = 0.885$, bigeye import equation $R^2 = 0.8561$

Table A3.2 Hypothesis Test of Scale Elasticity Equal to -1: $H_0: F_i = -1$

Scale Elasticity	Test Statistic Estimate	Standard Error	t-Statistic	Reject $H_0: F_i = -1$ (Yes/No)
Skipjack Landing	1.7634	0.0350	51.2624	Yes
Bigeye Landing	-0.0377	0.0804	-0.4679	No
Yellowfin Landing	-1.1861	0.0686	-17.2883	Yes
Skipjack Imports	1.9523	0.0544	35.8772	Yes
Bigeye Imports	0.0066	0.0947	0.0692	No
Yellowfin Imports	0.8219	0.01213	67.7823	Yes

Note: Linearized standard errors in parentheses. Test statistic calculated at sample mean.
*** for 1% level of significance, ** for 5%, * for 10%.

A3. . Compensated Price Flexibilities

The compensated own- and cross-quantity price flexibilities, corresponding to the Antonelli decomposition of inverse demand (Antonelli 1886, Eales and Unnevehr 1994), are all uniformly inelastic, indicating that the scale effect plays a big part in the uncompensated flexibility magnitudes (Table 2). The compensated own-quantity price flexibilities are all negative and statistically significant at 1%. The compensated q-complementarity between yellowfin imports and skipjack landings price is consistent with the uncompensated q-complementarity. The compensated q-substitution between skipjack landings and yellowfin price and between yellowfin imports and yellowfin landings price differ from the uncompensated q-complementarity. Most compensated cross-quantity price flexibilities are statistically insignificant, in contrast to many of the uncompensated cross-quantity price flexibilities. These results highlight the importance of scale effects in the uncompensated flexibilities. A strong and influential scale effect is to be expected with joint production in harvesting and an economy open to tuna imports (and exports).

Table 2. Compensated Price Flexibilities

	Skipjack Landing Price	Bigeye Landing Price	Yellowfin Landing Price	Skipjack Import Price	Bigeye Import Price	Yellowfin Import Price
Skipjack Landings	-0.1232*** (0.0211)	0.0168 (0.0103)	0.0244* (0.0138)	-0.0567*** (0.0162)	0.0009 (0.0081)	-0.0190*** (0.0034)
Bigeye Landings	0.0705 (0.0433)	-0.1839*** (0.0627)	-0.0077 (0.0499)	0.0388 (0.0354)	0.0220 (0.0232)	-0.0604*** (0.0184)
Yellowfin Landings	0.0899* (0.0502)	-0.0067 (0.0434)	-0.1660*** (0.0504)	0.0763** (0.0282)	0.0105 (0.0235)	-0.0031 (0.0106)
Skipjack Imports	0.0765*** (0.0229)	0.0132 (0.0120)	0.0296*** (0.0109)	-0.1389*** (0.0260)	0.0024 (0.0121)	0.0172*** (0.0036)
Bigeye Imports	0.0662 (0.0558)	0.0306 (0.0408)	0.0212 (0.0474)	0.0126 (0.0628)	-0.1529*** (0.0565)	0.0143 (0.0125)
Yellowfin Imports	0.0473*** (0.0086)	0.0359*** (0.0109)	-0.0270 (0.0072)	0.0303*** (0.0062)	0.0049 (0.0042)	-0.9121*** (0.0154)

Note: Linearized standard errors in parentheses. Compensated scale flexibility calculated at sample mean.
*** for 1% level of significance, ** for 5%, * for 10%.

A4. Cointegration results

In order to scrutinize the relationship between the Manta and Bangkok markets, we estimated the cointegration relationship between the prices of the two species in both markets, following the Johansen maximum likelihood procedure (Johansen, 1988; Johansen and Juselius, 1990). The results are all available in the supplementary materials (Table A4.1 and Table A4.2). In particular, two bivariate VAR models were applied to the price of each species in the two marketplaces, showing in both cases a unique cointegration relationship and a bidirectional causality, although the law of one price was not validated. The two cointegration relationships are:

$$LEPSKJ_t - 1.3217.LTPSKJ_t + 2.4089 = \varepsilon_t \qquad \text{(A4a)}$$
$$LEPYFT_t - 1.5378.LTPYFT_t + 4.1171 = \varepsilon_t \qquad \text{(A4b)}$$

LEPSKJ is the logarithm of the Manta price of Skipjack, LTPSKJ is the log price of the Bangkok price, LEPYFT is the log price of yellowfin tuna in Manta and LTYFT is the log of the yellowfin price in Bangkok.

Bidirectional Granger causality was found for each market, meaning that no market fully dominates the other and market information circulates in both directions. This brings evidence that the EPO catches and the Manta market do matter for price settings at the worldwide level. However, the regressor of each cointegrating equation, which represents the elasticity of price transmission (% change from one market to the other one), is greater than 1, meaning that the Manta price reacts more than proportionately (i.e. 1.32%) to a 1% change of the Bangkok price (Eq. 10a). Conversely, whenever the price increases by 1% in Manta, the skipjack price in Bangkok would increase only by (1/1.32=0.76%). The magnitude of the response between the two yellowfin prices is similar: the Manta price reacts more to the Bangkok price than the other way around (Eq. 10b). For both species, it becomes possible to infer from Eq. (10a) and Eq. (10b) the price differential between the two marketplaces, around 80 or 90 USD per ton in favour of Bangkok, which must correspond more or less to the shipping cost between the two markets. In the supplementary materials, Table A4.1 and Table A4.2 present the full cointegration results that give more strength to the demonstration: the multivariate model VAR07 including the four prices (skipjack and yellowfin in Manta and Bangkok) shows clearly the influence of the Thailandese skipjack price over the three other prices through a Granger causality test, but also the feedback information that the Thailandese market receives from the two major tuna species sold in the Manta market when setting its own prices. This result would tend to validate the IAIDS scale flexibility results found in Section 4.1. If the Manta market price of skipjack is found so flexible in prices, this is certainly because of the reciprocal influence of Thailandese and Ecuadorian markets over global tuna trade.

Table A4.1 Bivariate/multivariate cointegration and LOP tests on the horizontal linkages between yellowfin and skipjack tuna prices following the Johansen maximum likelihood procedure (Johansen, 1988; Johansen and Juselius, 1990)

Price relationships	Null hypotheses for the cointegration tests[a]								LOP
	Rank=0		Rank=1		Rank=2		Rank=3		
	Max[b]	Trace[c]	Max[b]	Trace[c]	Max[b]	Trace[c]	Max[b]	Trace[c]	
LTPSKJ-LEPSKJ	27.53048*	35.84505*	8.314571	8.314571	-	-	-	-	6.022838*
LEPSKJ-LEPYFT	9.138922	14.75511	5.616184	5.616184	-	-	-	-	-
LEPSKJ-LTPYFT	27.0522*	33.30288*	6.250681	6.250681	-	-	-	-	12.68981*
LTPSKJ-LEPYFT	20.74516*	29.20675*	8.461582	8.461582	-	-	-	-	0.348099
LTPSKJ-LTPYFT	12.00932	20.86096*	8.851642	8.851642	-	-	-	-	2.463095
LEPYFT-LTPYFT	34.84362*	41.39622*	6.552602	6.552602	-	-	-	-	7.212467*

LTPSKJ-LTPYFT-LEPSKJ-LEPYFT	39.2884*	90.78818*	32.66719*	51.49978*	10.95275	18.83259	7.879839	7.8798	-

Note: Data Jan 2013: Dec 2020. A restricted constant and no centered seasonal dummies have been included. Akaike information criterion has been used. Critical values for the cointegration tests are provided by Pesaran et al. (2000). [a] *Null hypothesis: the number of cointegrating vectors is equal to zero, one, two or three.* [b] *Maximum eigenvalue test.* [c] *Trace test. * Significant at the 5% level.*

Table A4.2 Causality tests on the horizontal linkages between yellowfin and skipjack tuna prices

	ECM$[\varepsilon]_{t-1}$/LR statistics			
Price relationships	LTPSKJ	LEPSKJ	LEPYFT	LTPYFT
LTPSKJ-LEPSKJ	4.89725**	10.31999**		
LEPSKJ-LTPYFT		0.366507		20.64546**
LTPSKJ-LEPYFT	4.228605**		6.268263**	
LTPSKJ-LTPYFT	0.875184			3.136442*
LEPYFT-LTPYFT			4.868555**	20.59053**
LTPSKJ-LTPYFT-LEPSKJ-LEPYFT	12.5993**	16.47113**	6.297926**	22.00471**

*Note: * Significant at the 10% level; ** significant at the 5% level.*

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