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Integrated World Tuna Markets

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Abstract:	The Law of One Price (LOP) is a little bit like quantum entanglement: despite their functional or geographical distance, different markets with their own separate groups of buyers and sellers, can experience similar price changes, unrelated to local economic conditions, due to their economic integration. We test for LOP in the separate raw and canned tuna product world markets, where raw tuna is an input into canned tuna. The world markets for raw and tinned tuna products are interconnected, and we estimate a cointegrating long-run relationship between their prices that confirms LOP. In the long-run, the two markets are tightly integrated, with prices transmitted bilaterally between each. No evidence was found for transport costs creating price wedges. Short-term price adjustment - for a world market - is extremely quick: the two product markets equilibrated within 2-3 months of a price shock.

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14 July 2026

Re: Integrated World Tuna Markets Paper

Dear Sir / Madam,

Please find attached an economic paper for publication in Fisheries Research.

The paper looks at the world markets for raw and tinned tuna, and develops ideas and suggestions from an early published Fisheries Research paper, *Testing for market linkages between Hawaii and Japan's tuna markets* (doi:10.1016/j.fishres.2011.03.004)

The paper builds on data from the United Nations Comtrade imports and exports database and estimates the Law of One Price for raw and tinned tuna. It is important because it estimates these two markets for separate commodities are linked that changes in one affect the other. The paper also finds the concentrated world tinned industry structure is a consequence of the raw and tinned markets being tied together, and the raw market prices more "noisy" than tinned prices.

The code and data is available for review:
https://github.com/PacificCommunity/Tuna_World_Trade_Modelling

I hope you find it an interesting continuation from the prior work of Hui Huang and PingSun Leung in their Hawaii and Japanese tuna market paper.

Yours sincerely,

James Hogan

Integrated World Tuna Markets

08 July 2026

Abstract

The Law of One Price (LOP) is a little bit like quantum entanglement: despite their functional or geographical distance, different markets with their own separate groups of buyers and sellers, can experience similar price changes, unrelated to local economic conditions, due to their economic integration.

We test for LOP in the separate raw and canned tuna product world markets, where raw tuna is an input into canned tuna. The world markets for raw and tinned tuna products are interconnected, and we estimate a cointegrating long-run relationship between their prices that confirms LOP. In the long-run, the two markets are tightly integrated, with prices transmitted bilaterally between each. No evidence was found for transport costs creating price wedges. Short-term price adjustment - for a world market - is extremely quick: the two product markets equilibrated within 2-3 months of a price shock.

Introduction

Economic markets are magical things. The ability of competitive markets of willing buyers and sellers, transacting at arms-length from each other, to generate welfare-enhancing outcomes for both parties is unrivalled across different economic systems.

The Law of One Price (LOP), through market connectivity, is part of this economic magic. Prices in integrated markets will change together when supply and demand changes in either market, with sometimes surprisingly quick speed. *How* markets link depends on whether their products are complements or substitutes. The price change direction in both markets is unambiguously the same, which is why LOP is expressed with respect to price changes only, but the direction of the induced quantity change depends on the products.

Moving from the magical to the evidence-based, this paper develops insights from the previous fishing LOP economic literature to test vertical LOP market integration between the raw and tinned tuna markets using UN Comtrade world import/export data across the period 2011-2024. The start of the paper goes through LOP, and the techniques used for its measure. Secondly, the existing fish-related literature is summarised. This paper responds to the key points from the tuna-focused LOP research, but insights from earlier work are used to critique some of the tuna LOP findings.

Thirdly, the key insights from the UN Comtrade data are presented, together with the relative size of the two markets.

The econometrics are considered in the fourth section, together with their long and short-run interpretation. Long-run bilateral LOP is confirmed through both dynamic regression models (treating the data as stationary with a break) and cointegration analysis, including dummy variables for two identified structural breaks. LOP estimated through cointegration rejects the existence of a transport related price wedge in either price transmission equation.

The short-run price dynamics are extremely quick - world raw and tuna prices return to equilibrium in approximately two months. The short-run price differences also do not have their expected signs. Three reasons are suggested: tinned producers might be absorbing short-term price shocks through maintaining tinned price stability; the coefficient signs might be an artifact of inventory lag, if tinned producers are selling product processed from raw fish bought 3-6 months prior at a different price points now prevailing in the more volatile raw market, thirdly the "price decoupling" is exactly what would be expected from vertically integrated raw / tinned tuna producers.

Finally, the paper reconsiders some of the fish-related LOP literature in light of the findings from this paper. The concentrated vertical integrated market structure identified by (Jiménez-Toribio, Guillotreau, and Mongruel, 2010) is argued to be the long-run market response necessary for the higher valued tinned market to internalise the more frequent and variable price shocks received from the raw market. It is not the outcome of tariff or trade policy - it flows naturally from long run bilateral price transmission where the less valuable raw market transmits more price-variance into the more valuable tinned market.

Theory of Law of One Price

The static version of LOP is empirically estimated through the regression:

$$ln(p_t^A) = \alpha + \sigma ln(p_t^B) + \varepsilon_t \qquad Equation(1)$$

The intercept, α, captures transport costs that create a permanent cost-wedge between the two market prices. The slope coefficient, σ, captures the degree of substitutability between the products.

The LOP is the hypothesis test that:

$$H_0: \sigma = 1$$

If products A and B are imperfect substitutes or imperfect complements, price changes between p_t^A and p_t^B may not be fully transmitted between markets making $\sigma < 1$

Static LOP Price leadership

In Equation (1), changes in market B prices, “cause” changes in market A’s price. Reverse the order of prices in Equation (1), and the same model can be used to test whether changes in market A’s price “causes” changes in market B’s price.

If the prices *are each stationary series*, Granger Causality can be used to test unidirectional or bidirectional causality between prices.

If the prices *are not stationary series*, then Equation (1) becomes the functional form of the “long-run” cointegrating vector within an ECM. “Price leadership” is derived from which normalised form of the Error Correction Term (ECT) matches the form of Equation 1.

Dynamic version of LOP

Moving products across distances takes time and involves delay which can introduce time lags between price changes in different markets. The dynamic version of the LOP *with stationary data* is an autoregressive model of prices in their levels, including time lags on price changes in both markets:

$$p_t^A = a + \sum_{j=1}^{M} b_j \, p_{(t-j)}^A + \sum_{i=1}^{N} c_i \, p_{(t-i)}^B + \varepsilon_t \qquad Equation(2)$$

Long-run LOP is verified through testing that:

$$H_0 : \sum b_j + \sum c_i = 1$$

Dynamic LOP Price leadership

Market transmission is verified through rejecting a joint test that all

$$Ho : c_i = 0 \forall i$$

If this joint test *is rejected*, then one or more lagged values of $p_{(t-i)}^B$ *do* statistically affect p_t^A which also helps time the price transmission process. Footnote 14 in (Asche, Gordon, and Hannesson, 2004) describes this result as a test for Granger *noncausality*.[1]

Between two time series, $p_{(t-i)}^B$ and p_t^A one series "Granger causes" the other if information about the history of one series improves the ability to predict the behaviour of the other. Price leadership can be tested through Granger Causality from a vector autoregressive model.

[1] (Granger, 1969)

Non-stationary Data and Cointegration

When prices are non-stationary, all of the above standard regression techniques are invalid and cointegration techniques are needed. Johansen's Method of cointegration estimation and testing as a system of equations is the dominant methodology favoured in the literature for non-stationary data.

Cointegration occurs when a linear combination of two of more non-stationary variables can be formed which produces stationary residuals. Finding cointegration *is* evidence of a stable long-run relationship between the series (Engle and Granger, 1987b) and the two series can be described as being in statistical equilibrium. If two series are cointegrated then, in the short-term, they may depart from their long-run equilibrium relationship, but there will always be a tendency for each to separately "adjust" back towards the long-term equilibrium relationship again.

Error Correction Models and Johansen's Method

An ECM is a statistical model expressed in matrix form which captures any "long-run" cointegrating relationships in the data vectors and the statistical effects of short-run deviations from equilibrium (Equation (3)).

$$\mathit{\Delta} P_t = \sum_{i=1}^{k-1} \mathit{\Gamma}_i \, \mathit{\Delta} P_{t-1} + \mathit{\Gamma}_K P_{t-k} + \mu + \varepsilon_t \qquad Equation(3)$$

An ECM includes an ECT - $\mathit{\Gamma}_K P_{t-k}$ - which is a linear combination of the variables in their levels and captures the concept of a long-term equilibrium relationship existing within the data. The ECM also includes vectors of lagged prices in their differences - $\sum_{i=1}^{k-1} \mathit{\Gamma}_i \, \mathit{\Delta} P_{t-1}$ - which captures the impact of prices upon each other when shocked from their equilibrium position and is, in practice, a Vector Auto Regressive (VAR) model of each data series in its differences.

Causality in Johansen's method: weak and strong exogeneity

Johansen's method estimates an ECM as a system of equations with combinations of price variables entering the model in both their levels and differences.

As a system, the ECT component: $\Gamma_K P_{t-k}$ is a matrix of prices in their levels representing any combination of potentially long-term relationships *between* some or all of the prices in the model. Whether any of the vectors of variables in the ECT matric are statistically valid models of long-term relationships between the combination of variables depends on the matrix rank of Γ_K

The Γ_K ECT component of the ECM can be further split into two components:

$$\Gamma_K = \alpha\beta'$$

Where α is a matrix of potential long-term relationships, and β' are the "loading factors".

The α matrix are price vectors with statistically estimated coefficients that capture the long-run relationships within the data.

The β' loading factors are the statistical coefficient on the point estimate of the ECT variable in each individual price series VAR. The loading factor measures the proportion of a disequilibrium shock corrected by each series within a period as it moves back towards long-run equilibrium. It is a 'speed of adjustment' measure which reflects the "strength" of the equilibrium relationship on each individual data series.

Weak and strong exogeneity

If the ECTs are statistically insignificant within any of the individual VARs of the ECM, then that price is "weakly exogeneous" with respect to the other prices. Weakly exogeneous prices cannot, in the long run, cause other prices to change, and the prices do not come from an integrated market.

If the ECT term is insignificant within a specific VAR, and none of the other short-term price differences are statistically significant, then the price measured through the VAR is "strongly exogeneous" with respect to the other prices: there is no short-term nor long-term relationship between this price and the other prices.

If short-term price differences are statistically significant with a specific VAR then two or more price series can be influenced by short-term dynamics with each other but they do not, and will not, be derived from a common integrated market unless the ECT is also statistically significant.

Existing literature

There is a surprising wealth of fish-related Law of One Price economic research.

A Fish Is a Fish Is a Fish? Testing for Market Linkages on the Paris Fish Market (Gordon, Salvanes, and Atkins, 1993)

Gordon, Salvanes and Atkins's research investigated a belief that high and low priced fish traded in two separate product markets. The authors tested whether salmon and turbot - two high-priced raw fish species - were sold in separate product markets from cod, a cheaper fish.

All three fish prices were found to be I(1) and non-stationary. Using Johansen's method, the authors found evidence of one cointegrating long-run equilibrium relationship between the prices of salmon, cod and turbot. However, the estimated Johansen cointegrating vector implied cod and turbot prices were related to each other, but salmon prices were both weakly and strongly exogenous from turbot and cod prices.

Salmon did not share a common market with turbot and cod: cod and turbot shared one market; salmon had its own. At the wholesale level, cod and turbot could not be substitutes for salmon. Consequently, frozen salmon supply could not affect high-valued turbot prices, or low-priced cod.

On Prices of Fresh and Frozen Cod Fish in European and U.S. Markets (Gordon and Hannesson, 1996)

Gordon and Hannesson investigated both the long-run and short-run price relationships of whole fresh cod and frozen cod fillet imports across three European countries: France, Germany, and the United Kingdom (UK), as well as the geographically separate United States (USA). All four countries imported substantial amounts of fresh and frozen cod product from Canada, Iceland, and Norway.

Gordon and Hannesson treated fresh whole cod and frozen cod as two products traded in separate markets which operated in different locations. For both fresh and frozen cod products, the price series were I(1) for all countries; however, later analysis using Johansen's cointegration method suggested that USA fresh cod prices were I(0).

For whole fresh cod, no evidence of cointegration of prices among the four countries was found. There was no support for long-run price linkages for fresh cod in the European and USA markets. There was also either no or weak evidence of market integration across the four countries. Dropping the USA fresh cod price, and re-testing for cointegration revealed one cointegrating vector for just the European countries. The USA and European markets for fresh cod were not integrated. Prices for fresh cod could deviate substantially from each other between the separate geographic markets.

Tests For Market Integration and the Law of One Price: The Market For Whitefish in France (Asche, Gordon, and Hannesson, 2004)

The authors chose to explore prices for whitefish products (cod, haddock, redfish, and saithe) in France. All prices were tested and treated as I(1) and modelled as different combinations of price pairs which were all cointegrated. The results suggested the different whitefish species, except redfish, could all be treated as one single "whitefish" product type. A long-run stable equilibrium relationship operated between cod, haddock, redfish, and saithe prices with cod as the price-leader.

The authors believed that, together with market integration results reported elsewhere, there existed a world market for frozen cod fillets; therefore, one global market for frozen whitefish fillets.

Is There a Global Market for Tuna? Policy Implications for Tropical Tuna Fisheries (Jeon, Reid, and Squires, 2008)

This is the first paper to deal with pacific tuna and horizontal market integration, with the authors motivated by tuna conservation. Tuna stock assessments indicated bigeye had been overfished in the western central Pacific Ocean for several years. Both species were also overfished in the Atlantic and eastern Pacific Oceans at the time. The paper focused on whether the regional tuna markets in Europe, West Africa, the Americas, American Samoa, Thailand, and Japan were separate or integrated.

The methodological approach was novel. Skipjack tuna was the largest caught species by a sizable margin and supplied tinned tuna canneries in a number of regions. Yellowfin tuna was sold to canneries in a subset of these regions. Only in two regional markets were *both* skipjack and yellowfin sold. If the authors could establish that skipjack and yellowfin were different species traded in a larger common market, then threatened yellowfin quantities would respond to skipjack-generated price dynamics, presumably as product complements[2], as seen via activity in the two locations - Bangkok and Tokyo - where each species were both traded together.

Results

The short-run effects in skipjack prices were considered using the Granger noncausality concept, implicitly treating the price series as I(0). Their pricing data was also plagued by missing time periods for some of the regions. Japan and Spain were missing skipjack prices between 1989 – 1994. All six location prices were present over the 1995 - 2001 period. Unlike previous papers, the authors did not first test for the presence of unit-roots within their pricing data, but instead, ran causality tests as if the data was stationary, and then cointegration tests as if the data was non-stationary.

The authors found over the 1989 - 1994 period, Bangkok skipjack prices weakly influenced Abidjan and American Samoan skipjack prices. Bangkok was only a modest price-leader. The skipjack regional markets were segregated over this timeframe. In the second time period, 1995 - 2001, the market dynamics dramatically changed. Latin America became the new skipjack market price-leader, strongly affecting the Bangkok market. Abidjan and Spain were price followers. No investigation into the cause of the rapid regional market leadership reorientation between the two data sets was undertaken.

[2] While prices move one way in both markets, quantity can move either way across the markets. If skipjack and yellowfin were substitutes, then increased skipjack catch quantities would *protect* yellowfin stocks as yellowfin demand decreases with transmitted price declines. If skipjack and yellowfins were complements, then increased skipjack catches and price increases would translate into increased yellowfin price and quantity changes. Without knowing the complement/substitute nature of the skipjack to yellowfin, it does not necessarily follow that skipjack-induced price changes will undermine yellowfin conservation efforts.

For the period 1995 to 2002, containing all six of the regional prices, cointegration tests for skipjack prices yielded only one cointegration vector "indicat[ing] the existence of undoubted price co-movements among the six skipjack markets in the long-run".[3]

No further description of this result was forthcoming. The authors did not estimate an ECM model which could be used to identify weak/strong exogeneity, nor use Johansen's method to estimate the ECT and test its rank for the number of cointegrating relationships between the prices in different locations. They did not estimate the VARs for each skipjack price in each location, and they did not explain why 4 lags were chosen in their cointegrating model.

If they had estimated an ECM, they could have tested through the rank of the ECT how many cointegrating vectors existed in the data. There could have been a maximum of 5 combinations of valid ECTs, being (n-1), if skipjack prices in these six locations did indeed all share a common factor shaping their change over time. However, no such analysis was undertaken.

Yellowfin prices were found to be nonstationary in Bangkok and Italy, but stationary in Tokyo. Cointegration tests were undertaken on Bangkok and Italian yellowfin prices, with no cointegration found.[4] A spatially integrated yellowfin tuna market could not exist between the three traded locations.

[3] (Jeon, Reid, and Squires, 2008) page 40

[4] *ibid* on page 43

Global integration of European tuna markets (Jiménez-Toribio, Guillotreau, and Mongruel, 2010)

Of the prior research, (Jiménez-Toribio, Guillotreau, and Mongruel, 2010) is the closest in nature to the present paper, but also the most complicated in its data sources, assumed economic relationships and empirical methodology.

Picking up from (Jeon, Reid, and Squires, 2008), the authors sort to extend the previous research to include more European markets and estimate the spatial market integration between the two main tuna species, and the canned tuna markets. Like (Jeon, Reid, and Squires, 2008), their motivation was conservation. They perceived an integrated tuna market would undermine individual Regional Fisheries Management Organisations tuna conservation efforts, but with some very strong normative assumptions regarding market failure.

Their thinking

If tuna markets were integrated, then competition between tuna processors for caught tuna would be high. Caught tuna would arbitrage across geographies, from the cheapest fisher to the most expensive processor, to generate the integrated equilibrium market price. But fishers, operating in a specific local area, would find their incomes would fall if tuna became depleted in their location.

Falling catch volumes, sold to tuna processors who would pay only the relative integrated equilibrium market price would result in falling fisher incomes. To compensate, fishers would *increase* their effort and *further* deplete their local stocks in order to maintain their incomes: "[they] would receive no incentive toward reducing their catches". Even worse, tinned producers, who were judged by the authors to be oligopsonistic, would "be blind to the extremely low raw material prices induced by [their] own market power", and would contribute to "perverse incentives" over several, unspecified, integrated raw tuna markets.

The authors believed the European tinned tuna markets were imperfect, and that market imperfections "could impact tuna exploitation systems", referring to the tuna fishing industry.[5] They wrote:

> *The probability of market imperfections on the downstream side of the supply chains is evident in the low levels of horizontal integration between final product markets, or by the low levels of vertical market integration between raw material and final products. … the signal of tuna resource scarcity might not be fully transmitted through higher prices to the retailers or consumers who would otherwise turn their procurement to other products or species.*
>
> – (Jiménez-Toribio, Guillotreau, and Mongruel, 2010) page 167

Which seems to mean:

1. There exists 'low levels of horizontal integration between final product markets'. Fish retailers do not offer different species of raw or tinned fish, nor products from different geographic origins to customers.

2. 'low levels of vertical market integration between raw material and final products'. Supply relationships between specific tuna fishers and tinned producers are permanent in duration and unchanging between the parties.

3. Both 1 and 2 above created "imperfections" within the fishing industry (the "downstream side of the supply chain"). These market imperfections suppressed

[5] "The analysis attempts to determine where integration ends and where market imperfections may occur; this article will examine why and how such market imperfections could impact tuna exploitation systems."

> price signals to retailers and consumers of tuna's scarcity. If prices are set in Bangkok and transmitted to other places, local prices only respond weakly to local changes in landings.

The authors undertook three sets of analysis. Like in the present paper, they explored vertical LOP between the raw and tinned tuna markets. Unlike the present paper, they defined the markets as specific geographic locations. Their focus was testing horizontal LOP between the predetermined separate raw and the tinned product markets. They did not explicitly test that raw and tinned tuna markets were connected through a production input/output relationship which the current paper specifically does.

Different markets delineated by price

The authors referenced (Gordon, Salvanes, and Atkins, 1993) in their work, but reintroduced the exact same high/low price market delineation that the prior paper explicitly tested and rejected: prices, by themselves, do not define functionally separate markets. (Jiménez-Toribio, Guillotreau, and Mongruel, 2010) asserted high / low prices were driven by "cheap" skipjack tuna sold to the Northern European countries of France, Germany and the United Kingdom, and "higher priced" yellowfin-based canned tuna sold to Italy and Spain.

The authors treated both markets as separate from each other, arguing:

> *the hypothesis lies in a possible segmentation of the European market for final goods between the Northern European countries (UK, and Germany) consuming low-priced skipjack-based products imported from Asia (mainly Thailand and also the Philippines) and the Southern European countries (Italy, and Spain) processing and importing yellowfin-based products sold in their domestic markets at higher*

prices. France presents an intermediate situation in which both markets provide a significant part of the national canned tuna consumption.

– (Jiménez-Toribio, Guillotreau, and Mongruel, 2010) page 167

The authors interpret their lack of results as evidence of market failure, as opposed to potentially erroneous assumptions, like market delineations based on price:

Therefore, in a last set of estimations, price relationships are tested vertically between the price of frozen tuna paid by the canneries, the price of canned fish at the processing level in Italy, and at the retailing level in France (Section 4). A weak or bad transmission of price signals along the value chain will be interpreted as first evidence of market power exercised either by the processors or the supermarket chains.

– (Jiménez-Toribio, Guillotreau, and Mongruel, 2010) page 167

Results

The authors found that cheap tinned skipjack tuna was integrated in the Northern European countries, but the more expensive yellowfin tuna was not. They argue this result is because: (1) European canneries product differentiate their brands, and (2) they benefit from a preferential trade regime where processing is undertaken in subsidiary canneries in Africa, Latin America or in some small island countries (Pacific and Indian oceans), and the use of raw tuna supplied by the European fleets they have invested in.

The raw and tinned yellowfin markets were not integrated. Explaining their result, rather than questioning their applied assumptions the authors believed, “there is potentially some distortion within the yellowfin value chain for an unknown reason”.[6]

[6] (Jiménez-Toribio, Guillotreau, and Mongruel, 2010) page 171

Testing for market linkages between Hawaii and Japan's tuna markets - (Huang and Leung, 2011)

Of the tuna-focused LOP fish-literature, (Huang and Leung, 2011) stands out as the best example of the test of LOP for both its clarity and its simplicity. The motivation for their research was they found the international tuna markets' integration was an interesting empirical question. If price linkages were observed, international price shocks would have short-run effects on the local market. In the long-run, all prices from linked international markets must equilibrate. Since Hawaii's tuna market is dynamic and intrinsically tied to a larger market, trade policy or fishery management changes in Japan as well as the demand and supply outside Hawaii will to a large extent shape the local Hawaiian tuna market.

Hawaii, was an important producer and consumer of tuna, and regarded as part of a larger network of inter-connected worldwide markets which included Fiji, Tonga, Marshall Islands, and the Philippines. Domestic consumption was the main source of tuna demand but a substantial amount was also exported to Japan, the mainland US, and, to some extent, Canada and Europe. Hawaiian exporters and fishers targeted Japan's tuna markets because of its high profitability and high demand for high quality tuna.

Bigeye tuna represented the largest component (40%) of the total landings, followed by yellowfin tuna (12%). Around 77% of internationally exported yellowfin from Hawaii was destined for the Japanese market. Back in 2001, the high value of sashimi-quality bigeye sold on Japan's market drove the international longlining fleet of all oceans.

Results

The LOP test for Hawaii regressed on Japan was not rejected. The prices from the two markets adjusted toward equilibrium in the long-run, even though this process may not be significant in the short-run. Causality was observed in one direction: Japan's price significantly influenced Hawaii's price, while Hawaii's price had no influence on Japan's. Bigeye tuna prices in the Hawaii and Japanese markets were integrated. Japan was the price leader and served to stabilise Hawaii's tuna prices.

Cointegration was used to explore yellowfin prices. There was no evidence of a cointegrating vector in yellowfin tuna prices between Japan and Hawaii. The authors also felt, product substitution in the long-run most likely exists for different species of tuna, including bigeye, yellowfin, skipjack and albacore. Further, Japan's and Hawaii's markets might be part of a globally integrated market and as such may interact with tuna markets elsewhere. If this is the case, integration should be examined in a way that includes all tuna species throughout the entire world market.

These last points motivated the development and approach of the current paper.

The Data

UN Comtrade Data Set

The United Nation's (UN) monthly Comtrade[7] trade data for the period January 2011 - December 2024 was used for this analysis. The Comtrade data reports monthly aggregated country level trade data by Harmonised Commodity System (HCS) code. Tables **13** and **14** in the Appendix describe the specific codes used for this analysis. All codes used kilogrammes of weight as their units of measure, and were expressed in nominal US dollars.

In this paper, "raw" tuna is being used to capture fresh, chilled or frozen tuna products across all tuna species types, but excluding tuna fillets, as described in HCS codes in Tables **13**. Tuna fillets are less likely to be inputs into tinned tuna, and are more likely to be final products in their own right.

[7] https://comtradeplus.un.org/

The relative size of the raw and tinned tuna markets

Figure1 **1** presents the relative sizes of the two world markets, by calendar year.

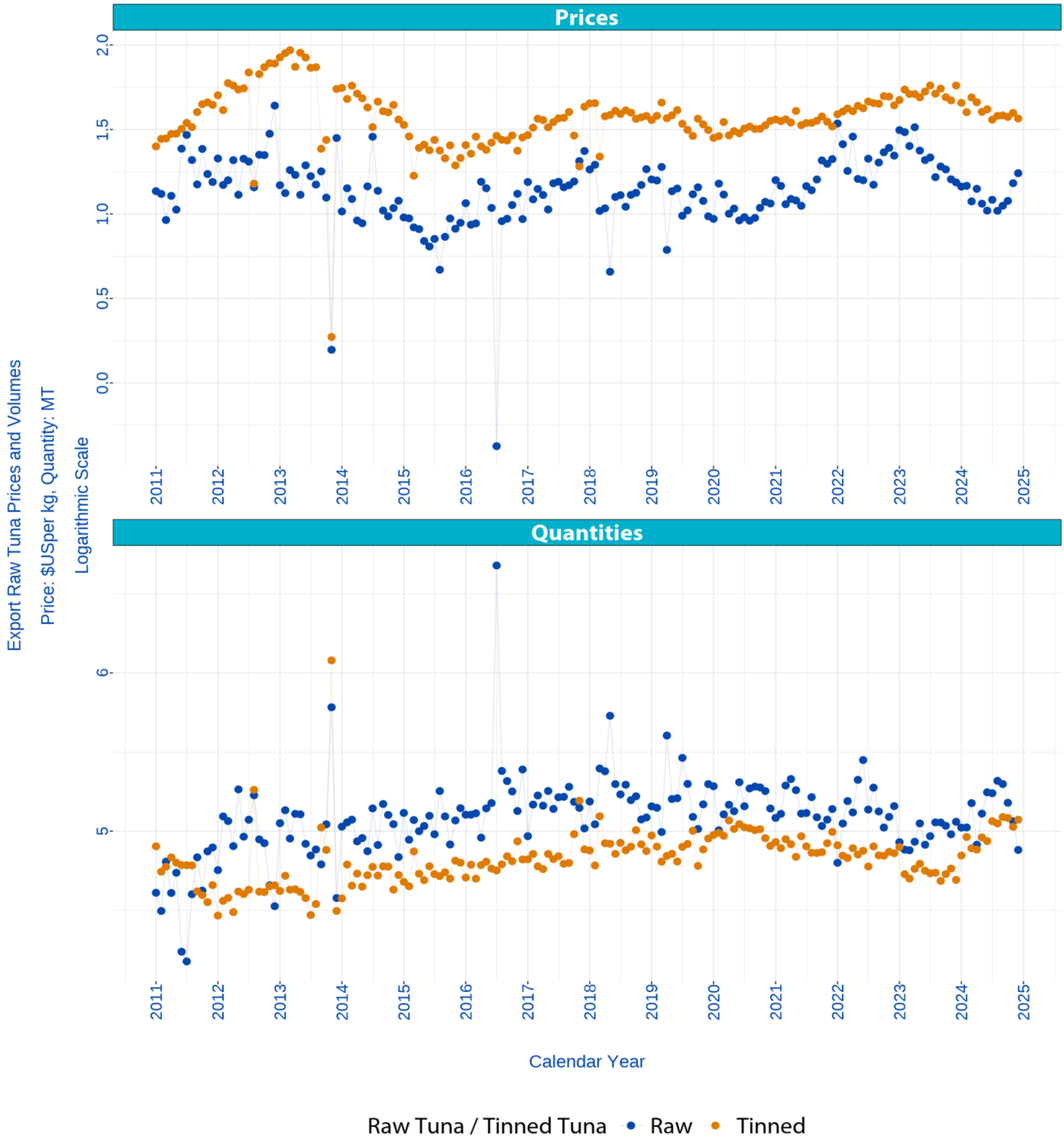
Figure 1: *World Quantities & Values*

The quantity of raw tuna globally traded significantly exceeds the quantity of tinned product traded. However, the story is reversed when comparisons are made on value. By value, tinned tuna is a higher global earner compared to raw tuna.

Figure **2** presents the underlying monthly seasonally adjusted prices and quantities in logarithmic form. The X12-SEATS seasonal adjustment programme was used to seasonally adjust both estimated average prices (primary value divided by net weight), and weight measures directly.

The raw market, both in prices and quantities, shows significantly more monthly variation compared to the tinned market. The early time period of the tinned market is dominated by increasing prices until around 2013 when prices decreased for three years before stabilising at a slower growth rate. Over the data's time period, the global quantity of both raw and tinned tuna has shown a moderately increasing rate of growth over time.

Figure 2: *World Export Prices and Quantities - Logarithmic Scale*



A tuna is a tuna is a tuna - what matters is its price

Picking up on (Huang and Leung, 2011), this paper treats all raw tuna species as perfectly substitutable. In addition, caught fish varies in quality which is reflected through price. Unlike (Jiménez-Toribio, Guillotreau, and Mongruel, 2010), no attempt has been made to assign the specific species to canning processes. All tuna, regardless of species are perfectly suitable for canning.

Figure **3** and **4** presents how both raw and canned tuna prices have varied by price deciles and over time, split by import/export measurement UN Comtrade data source. The top 90% - 100% decile is removed since it contains both exceptionally high-priced tuna, and observations with data error.

Perfectly substitutable preferences imply canneries will select tuna species on price. In Figure **4**, the most expensive tinned tuna sells for approximately a long-run average price of USD 13 per kilogramme, while the most expensive raw tuna sells for approximately USD 22 - 24 over the long-run. A profit maximising cannery will purchase low priced raw tuna, moving up the price deciles, until the margins between their output tinned prices and input raw prices are no longer economical.

It just so happens that skipjack tuna is both plentiful and caught through purse-seine fishing methods which lands tonnes of tuna at a time. Its large catch makes its price low, which accounts for its predominant use in the canning industry.

Any other species, caught in similar quantities, would produce similarly low prices, and probably find itself in a can.

Figure 3: *Raw Tuna Price Deciles - All Species*

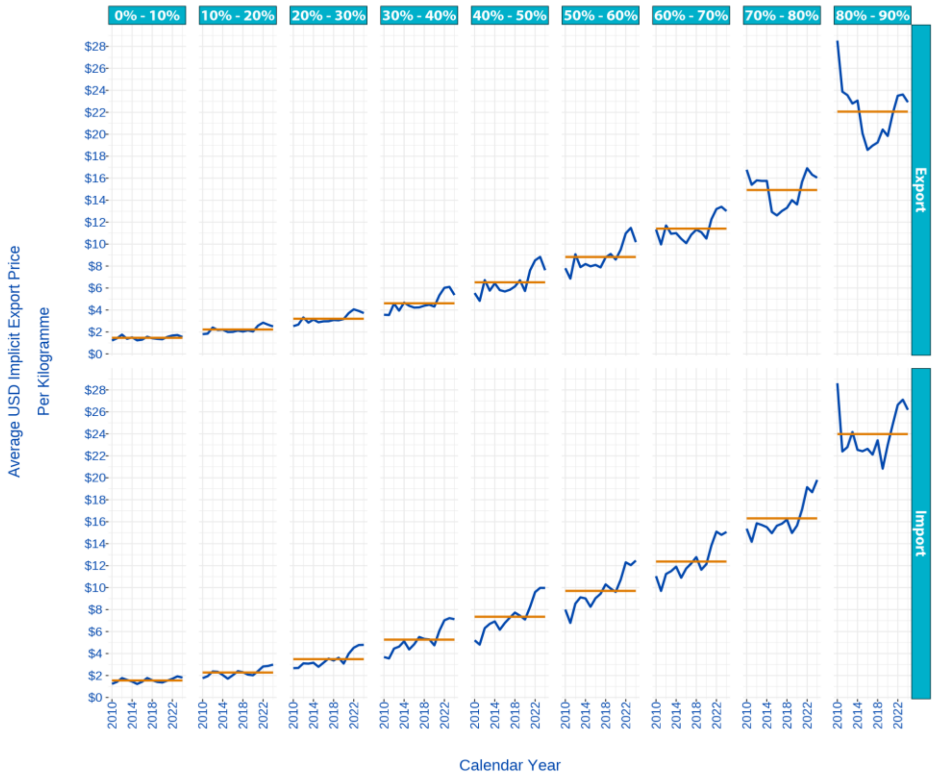
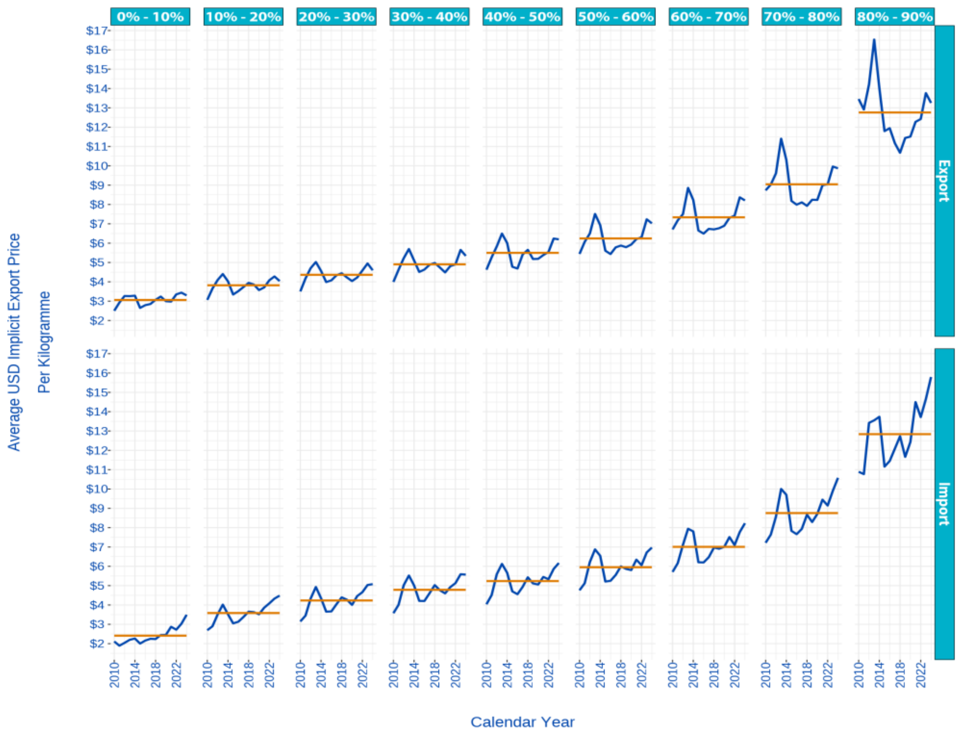


Figure 4: *Tinned Tuna Price Deciles*



Who are the world traders?

The world tuna story, is a Pacific story.

Figures **5** and **6** presents the major imports/exports of raw tuna, and the corresponding tinned tuna market based on imported/exported tuna weight. In these pictures, countries who collectively represent less than 5% of the world markets have been grouped into a single group called, the "Minnows". Most Minnows are both importers and exporters.

Any imbalances between export and import quantities have been assigned to a nominal country called "missing" depending on which side of the imports/exports side was smaller. For example, a significant proportion of raw tuna export data has their country origin unidentified. Whereas, on the tinned tuna side, a significant number of imported tinned tuna products are unidentified. Comtrade is a live database, and overtime, as countries update their records, the imbalances will probably reduce.

Raw tuna markets

The raw tuna market is dominated by pacific region countries: Federated States of Micronesia, Papua New Guinea, Nauru, Fiji, Marshall Islands, Australia, Tuvalu are all identified as large sources of raw tuna product. Within the broader Asia region feature South Korea, Indonesia and a large chunk of "Other Asia nec", meaning Comtrade could not reliably identify the country of export origin.

Thailand dominates raw tuna net imports by a very large margin, reflecting its role in the tinned tuna market. Almost certainly, the imported tuna into Japan are on the high-end of raw tuna's pricing spectrum. China is both a significant importer and exporter of raw tuna, with their own fishing fleet engaged in catching and processing raw tuna products, as well as purchasing product from elsewhere.

In the canned tuna market, the countries who are strong importers of raw tuna, are also dominant exporters of tinned tuna: Thailand, China, Philippines, and Ecuador. Their largest customers are the USA, and Europe.

Figures **5** and **6** describe the raw and tinned tuna trade markets from an import/export perspective.

Figure 5: *Raw Tuna Exports and Imports: 2024*

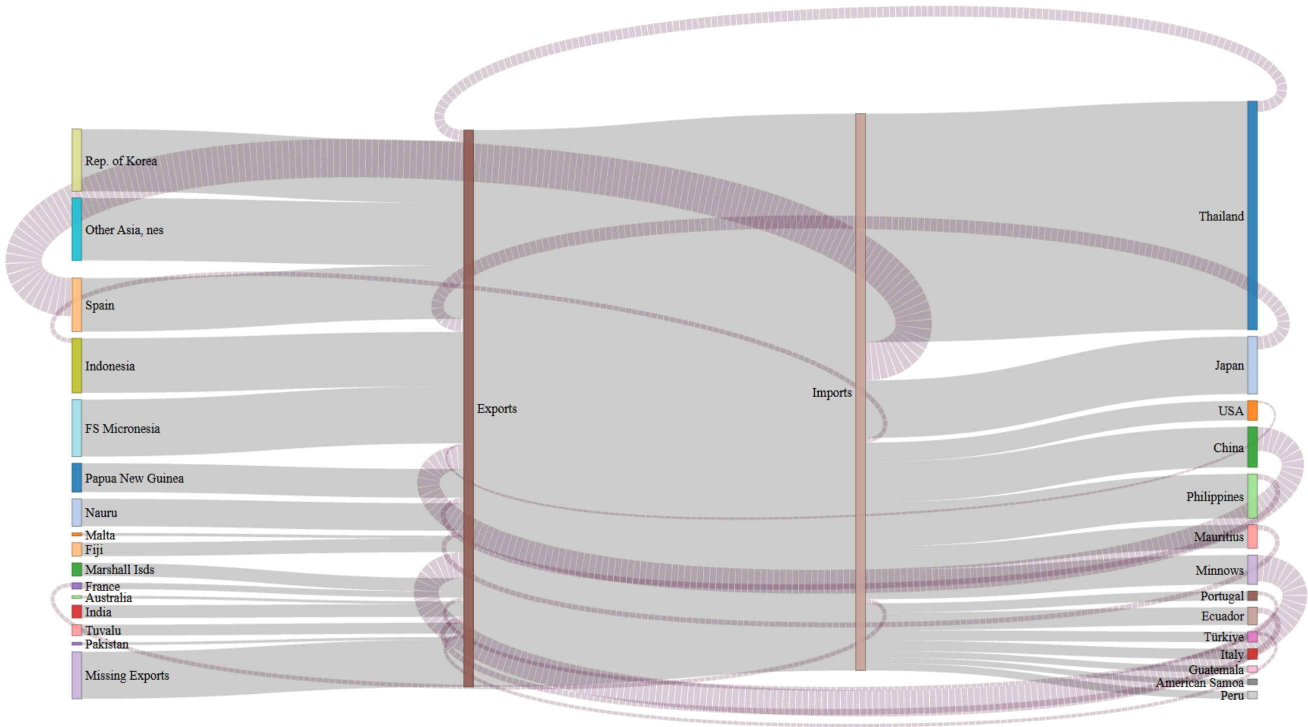
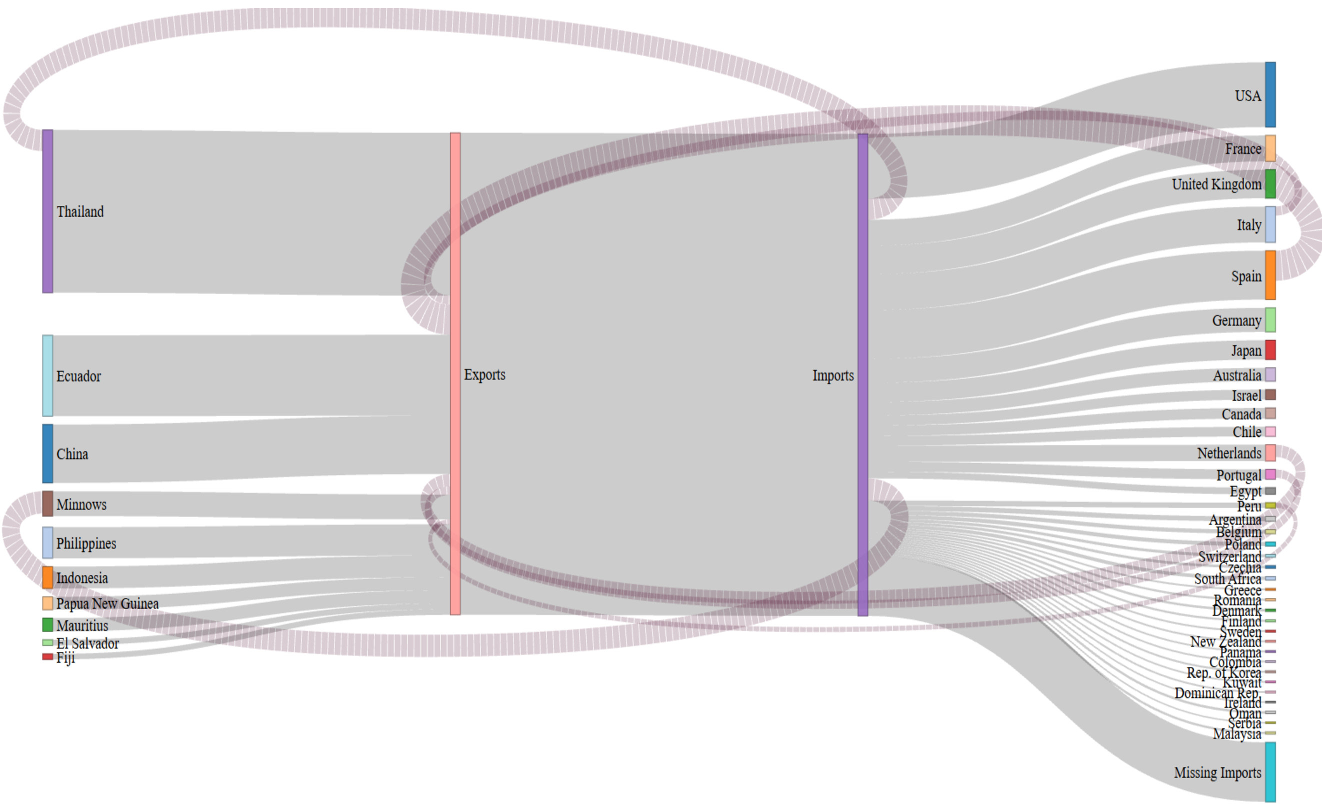


Figure 6: *Canned Tuna Exports and Imports: 2024*



Econometric results

Unit-root test results

Testing for stationarity involves testing whether each price time series can be expressed as an autoregressive process containing a unit-root. The Augmented Dickey-Fuller (ADF) test estimates the following equation:

$$\Delta p_t = \beta_0 + \beta T + \sigma p_{t-1} + \sum_{\gamma=1}^{k} \alpha_\gamma \, \Delta p_{t-\gamma} + \varepsilon_t$$

Where $\Delta p_t = p_t - p_{t-1}$ The number of lags, $\sum_{\gamma=1}^{k} \alpha_\gamma \, \Delta p_{t-\gamma}$ is chosen to ensure ε_t is white noise.

The ADF tests the null and alternative hypotheses:

$$Ho: \sigma = 1$$

$$H_A: \sigma < 1$$

Unfortunately, the ADF test is sensitive to the number of lags included in the regression. In practice, metrics like the Akaike Information Criteria (AIC) are used to choose the lag length.

Alternative tests exist and have also been included in Table **1** below. The additional tests are:

- The Kwiatkowski–Phillips–Schmidt–Shin (KPSS) unit root test.

  The KPSS tests the null hypotheses that a series is stationary around a deterministic trend, against the alternative hypotheses that it contains a unit root. Rejecting the null hypotheses is evidence that the series contains a unit root.

- The Phillips-Perron (PP) Unit Root test.

  Like the ADF test, the PP test estimates an autoregressive model to test for a unit root in the lagged timeseries. It differs from the ADF through making a non-parametric adjustment to the t-test used to test the presence of a unit root to correct for autocorrelation and heteroskedasticity which would expand the point estimate confidence interval.

- The Zivot-Andrews (ZA) Unit Root test.

  The Zivot-Andrews (ZA) is a variation of the ADF but tests for the presence of one structural break in the data. Structure breaks can make the data look like it has a unit root instead of trend stationary with a break. The null hypothesis of the ZA test is the data has a unit root test. Rejection of the null implies the data is stationary around with a break which can be dated from the data.

Stationary or Non-stationary?

The ADF, PP and the ZA tests, test the null hypotheses that the data *has* a unit root and the time series are non-stationary. If the test is rejected, then the series *do not* have a unit root, the data is stationary, and the autoregressive models can be used to test for market integration, and Granger Causality can be used to test for price leadership.

The KPSS has a different null hypothesis. It assumes the data is trend stationary, and it *does not* have a unit-root. If the KPSS test is rejected, then the data series *is not* stationary around a trend and *does* have a unit root.

If a series is stationary, then both the ADF, PP and the ZA tests should *reject* their null hypotheses, and the KPSS should *accept* its null hypotheses.

Table **1** below implements the ADF, KPSS, PP and ZA tests for raw and canned tuna prices, in both the levels and the differences. The lag length of the ADF was chosen through maximising the AIC statistic over a possible range of 24 months.

In the levels, the tests disagree on the order of integration for the different series. The ADF, PP and ZA tests strongly reject the hypothesis of a unit root in the levels in both prices. But the KPSS statistic strongly rejects the hypothesis that the data is stationary. Three of the four metrics say stationary - one says non-stationary.

In the differences, all four tests are in agreement. The ADF, PP, ZA and KPSS strongly reject the hypothesis of a unit root in the differences of the series, making the differences I(0) and all strongly stationary.

The lack of agreement between the unit-root tests in the levels is disappointing, but also not unknown within the literature.

Table 1: *Unit Root Tests on Prices*

			ADF Test			KPSS Test			Phillips-Perron			Zivot-Andrews					
Levels or First Differences	Time Series	No. of ADF Lags	No Intercept No Trend	With Intercept/ No Trend	With Intercept/ With Trend	No Intercept No Trend	With Intercept/ No Trend	With Intercept/ With Trend	No Intercept/ No Trend	With Intercept/ No Trend	With Intercept/ With Trend	With Intercept/ No Trend	Intercept/ Break Point	With Trend/ No Intercept	Trend/ Break Point	With Intercept/ And Trend	Both/ Break Point
Levels	Raw Prices	3	-0.403	-3.729 ***	-3.752 **	1.321 *	0.456 *	0.334 ***	-0.908	-111.447 ***	-112.896 ***	-9.971 ***	Sept 2013	-9.72 ***	Jul 2015	-10.156 ***	Aug 2016
	Tinned Prices	2	-0.269	-4.482 ***	-4.464 ***	0.466	0.283	0.281 ***	-0.231	-94.939 ***	-95.032 ***	-9.761 ***	Aug 2013	-8.574 ***	Dec 2015	-11.042 ***	Aug 2013
Differences	Raw Prices	4	-10.313 ***	-10.281 ***	-10.249 ***	0.016	0.016	0.015	-203.799 ***	-203.798 ***	-203.813 ***	-21.24 ***	Jun 2016	-20.989 ***	Jan 2011	-21.219 ***	Jun 2016
	Tinned Prices	14	-10.466 ***	-10.434 ***	-10.405 ***	0.03	0.020	0.020	-214.465 ***	-214.459 ***	-214.439 ***	-21.44 ***	Oct 2013	-21.185 ***	Aug 2013	-22.391 ***	Oct 2013

Notes: * indicates significance at the 10% level; ** indicates significance at the 5% level; *** indicates significance at the less than 1% level.
The ADF tests the null hypothesis that the data is non-stationary. Lag length chosen by maximum AIC statistic. KPSS tests null hypothesis that the data is level or trend stationary. Phillips-Perron test null hypothesis that the data is non-stationary.
KPSS Levels Lag = 2, KPSS Difference Lag = 2
PP Levels Lag = 4, PP Difference Lag = 4

Dynamic Regression: As if Stationary

Table **1** suggests the data is trend stationary, and probably with structural breaks around 2013 and 2016 based on the ZA timings. Consequently, dummy variables were generated for two periods: Jan-2010 to Dec-2013, and Jan-2014 to Dec-2016 picking up the turning points in prices in Figure **2**, and broadly in lines with the dated breakpoints in Table **1**.

Tables **2** and **4** represent the ordinary least squares-generated dynamic LOP estimates with 3 lags chosen, and including the ZA unit-root test identified breakpoints.[8] The results identify two-way market integration between the raw and tinned tuna markets: tinned lagged prices are significant in Tables **2**, and raw lagged prices are significant in Table **4**.

The results also identify the Law of One Price holds in both markets, with

$$H_0: \sum b_j + \sum c_i = 1$$

holding in Tables **3** and **5**.

[8] An initial 12-lag regression was initially estimated and tested against a 6-lag model using an ANOVA test to determine whether the additional months added to the power of the model. If rejected, successive models were tested against smaller lag structures. For both raw and tuna dynamic regressions, three lags were the optimal models.

Table 2: *Dynamic Regression - Tinned Tuna Prices Cause Raw Tuna Prices to Change*

$$P_{Raw_t} = \alpha + \sum_{i=1}^{3} \mathrm{B}_i P_{Raw_{(t-i)}} + \sum_{i=1}^{3} \mathrm{B}_i P_{Tinned_{(t-i)}}$$

	Estimate	Standard Error	t value	Pr(>|t|)
(Intercept)	1.371	0.370	3.702	0.000***
Break Point Pre 2013	0.110	0.128	0.863	0.390
Break Point 2013 2016	-0.234	0.103	-2.279	0.024*
Lag1 Tinned	-0.079	0.071	-1.126	0.262
Lag2 Tinned	0.209	0.077	2.719	0.007**
Lag3 Tinned	-0.179	0.073	-2.435	0.016*
Lag1 Raw	0.390	0.085	4.561	0.000***
Lag2 Raw	0.033	0.090	0.362	0.718
Lag3 Raw	0.233	0.084	2.754	0.007**

*Signif. codes: 0 <= '***' < 0.001 < '**' < 0.01 < '*' < 0.05*

Residual standard error: 0.4595 on 147 degrees of freedom
Multiple R-squared: 0.4364, Adjusted R-squared: 0.4057
F-statistic: 14.23 on 147 and 8 DF, p-value: 0.0000

Table 3: *Dynamic Law of One Price - Tinned Prices Completely Transmit into Raw Prices*

Regression Variable	Lower Confidence Interval (95%)	Point Estimate	Upper Confidence Interval (95%)
Lag2 Tinned	0.059	0.209	0.358
Lag3 Tinned	-0.322	-0.179	-0.036
Lag1 Raw	0.223	0.390	0.557
Lag3 Raw	0.068	0.233	0.397
Sum of Significant Coefs	**0.028**	**0.652**	**1.276**

Table 4: *Dynamic Regression - Raw Tuna Prices Cause Tinned Tuna Prices to Change*

$$P_{Tinned_t} = \alpha + \sum_{i=1}^{3} \mathrm{B}_i P_{Raw_{(t-i)}} + \sum_{i=1}^{3} \mathrm{B}_i P_{Tinned_{(t-i)}}$$

	Estimate	Standard Error	t value	Pr(>|t|)
(Intercept)	1.365	0.450	3.034	0.003**
Break Point Pre 2013	0.346	0.155	2.226	0.028*
Break Point 2013 2016	-0.050	0.125	-0.397	0.692
Lag1 Tinned	0.369	0.086	4.306	0.000***
Lag2 Tinned	0.256	0.093	2.751	0.007**
Lag3 Tinned	-0.137	0.089	-1.539	0.126
Lag1 Raw	0.108	0.104	1.038	0.301
Lag2 Raw	-0.054	0.109	-0.494	0.622
Lag3 Raw	0.298	0.103	2.908	0.004**

*Signif. codes: 0 <= '***' < 0.001 < '**' < 0.01 < '*' < 0.05*

Residual standard error: 0.5582 on 147 degrees of freedom
Multiple R-squared: 0.5378, Adjusted R-squared: 0.5127
F-statistic: 21.38 on 147 and 8 DF, p-value: 0.0000

Table 5: *Dynamic Law of One Price - Raw Prices Completely Transmit into Tinned Prices*

Regression Variable	Lower Confidence Interval (95%)	Point Estimate	Upper Confidence Interval (95%)
Lag1 Tinned	0.202	0.369	0.536
Lag2 Tinned	0.075	0.256	0.438
Lag3 Raw	0.098	0.298	0.499
Sum of Significant Coefs	**0.375**	**0.924**	**1.473**

Granger Causality

Following, (Huang and Leung, 2011) just-in-case the data was I(0), Granger Causality was also estimated with a variable lag, creating Table **6**. Except for lag lengths 2 and 12, all of the causality tests identify raw prices as causing tinned prices to change. There is some evidence to suggest tinned prices cause raw prices to change, but the strength of the signal in the data is not as strong.

Table 6: *Granger Causality: Prices in the Levels "as if" I(0)*

Causality Hypothesis		Dynamic number of lags											
Measure	Direction	2	3	4	5	6	7	8	9	10	11	12	Causation finding
Prices Causality	Raw Prices Cause Tinned Prices to Change	1.14 (0.322)	3.17 ** (0.0246)	2.84 ** (0.0246)	2.51 ** (0.0304)	2.76 ** (0.0125)	2.36 ** (0.0234)	2.09 ** (0.0372)	2.08 ** (0.0312)	1.82 * (0.057)	1.65 * (0.085)	1.51 (0.122)	Raw prices cause Tinned prices to change. Some evidence that tinned cause raw changes
	Tinned Prices Cause Raw Prices to Change	3.58 ** (0.029)	2.57 * (0.0543)	1.93 (0.105)	1.67 (0.142)	1.54 (0.166)	1.43 (0.193)	1.66 (0.108)	1.58 (0.122)	1.40 (0.179)	1.30 (0.226)	1.27 (0.237)	

Notes: p-Values are reported in parentheses.
* Indicates significance at the 10% level; ** Indicates significance at the 5% level; *** Indicates significance at the less than 1% level

Cointegration Methods

Following the lag selection procedure suggested by Enders[9], an unrestricted VAR model with a lag order of six was estimated, and the properties of the VAR tested. If the model's diagnostics failed, shorter lag lengths were then considered.

With six lags, the VAR was free from autocorrelation, heteroskedasticity, but it failed a Ramsey Reset test for structural change. Several alternative lag selection criteria were considered, including the Final Prediction Error, the Akaike Information Criteria, and the Hannan-Quinn Information Criteria. All the metrics indicated the optimal lag length was 2 (Table **7**). With two lags, the VAR residuals were free from autocorrelation, heteroskedasticity, and satisfied the Ramsey Reset test indicating no structural change.

Table 7: *Lag Selection Tests*

Lag Test	Value
AIC(n)	2
FPE(n)	2
HQ(n)	2
SC(n)	1

The trace test was used to determine the cointegrating rank (r) for the ECM estimated in the Johansen method. With two price series involved in this model, the test became whether the two series were cointegrated (r = 1) or not (r = 0). From Table **8**, the r <= 1 is clearly significant at greater than 1% level, indicating raw and tinned tuna prices are cointegrated.

Table 8: *Johansen Cointegration Test Results*

		Critical Values		
Null Hypothesis	Test Statistic	10% Level of Error	5% Level of Error	1% Level of Error
r <= 1	22.13	7.52	9.24	12.97
r = 0	61.61	17.85	19.96	24.60

[9] (Enders, 2004), pp. 358-359

Long-term Error Correction Term - the Law of One Price

Table 9: *The Law of One Price: Raw Causes Tinned to Change*

$$ln(Tinned_{Price_t}) = \alpha + \sigma * ln(Raw_{Price_t})$$

Variables	Coefficients	Standard Error	Lower Confidence Interval (95%)	Upper Confidence Interval (95%)	p-value
Raw Tuna Prices	1.078	0.152	0.783	1.374	0.000***
Constant	0.324	0.179	-0.025	0.672	0.078*
Signif. codes: 0 <= '***' < 0.01 < '**' < 0.05 < '*' < 0.1					

Table 10: *The Law of One Price: Tinned Causes Raw to Change*

$$ln(Raw_{Price_t}) = \alpha + \sigma * ln(Tinned_{Price_t})$$

Variables	Coefficients	Standard Error	Lower Confidence Interval (95%)	Upper Confidence Interval (95%)	p-value
Tinned Tuna Prices	0.927	0.154	0.626	1.228	0.000***
Constant	-0.300	0.245	-0.779	0.178	0.188
Signif. codes: 0 <= '***' < 0.01 < '**' < 0.05 < '*' < 0.1					

Johansen's method produces an ECT matrix $\Gamma_K = \alpha\beta'$ which, from Table **8**, indicates α contains one cointegrating relationship between the two sets of prices.

The methodology normalises the values of α on the first variable, with other variables expressed relative to the normalised variable. The methodology provides no indication around *which* of the variables should be normalised, and which of the other variables are expressed "relative to" the normalised variable.

The identification of the normalised variable is important because it becomes the price which is "caused" by the linear combination of the other variables and describes the direction of long-run causality. Recourse is normally made to theory for why one normalisation is more theoretically consistent compared to another.

Tables **9** and **10** reflects the two normalisations possible in the data - both are statistically valid normalisations of α.

LOP has two theoretical implications:

(1) Prices are passed through proportionally or less than proportionally from one market to the other: $\sigma \leq 1$

and

(2) Transport costs create a non-negative price wedge between the two markets

$$\alpha \geq 0$$

For each σ in Tables **9** and **10**, the LOP null hypothesis of $Ho: \sigma = 1$ lays within the 95% confidence interval for each price point estimate. Consequently, the LOP - operating in the long-run between raw and tinned tuna - cannot be rejected from either interpretation of the long-run cointegrating regression. Regardless of which normalisation is correct, the validation of proportional price movement from LOP is estimated to be the same.

Tables **9** and **10** both match the theoretical predictions from LOP. Consequently, and consistently with the dynamic version of LOP in Tables **2** and **4** two-way price transmission between *both* the raw tuna and the tinned tuna market cannot be rejected from the data.

The α constant, measuring transport cost price differential for both normalisations in Tables **9** and **10** are not statistically different from zero suggesting transport costs do not feature in price transmission between markets.

The long run dynamics are both markets transmit price signals into the other, and the two world markets are very tightly economically integrated indeed.

Short-term price dynamics and price leadership

Table 11: *Short-term Dynamics - Do Tinned Prices Lead Raw Prices?*

$$\Delta Price_{Tinned_t} = ErrorCorrectionTerm + \sum_{i=1}^{2} \mathrm{B}_i \Delta Price_{Raw_{(t-i)}} + \sum_{i=1}^{2} \mathrm{B}_i \Delta Price_{Tinned_{(t-i)}}$$

Variables	Estimate	Standard Error	t value	p-value	
Long-term Error Correction Term	-0.309	0.087	-3.542	0.001	***
Break Point Pre 2013	-0.003	0.027	-0.099	0.921	
Break Point 2013 2016	0.044	0.028	1.576	0.117	
Tinned Prices - Lag 1	-0.344	0.097	-3.549	0.001	***
Raw Prices - Lag 1	-0.238	0.088	-2.715	0.007	***
Tinned Prices - Lag 2	-0.001	0.088	-0.014	0.989	
Raw Prices - Lag 2	-0.214	0.071	-3.017	0.003	***

Signif. codes: 0 <= '***' < 0.01 < '**' < 0.05 < '*' < 0.1
Residual standard error: 0.1543 on 158 degrees of freedom
Multiple R-squared: 0.3036, Adjusted R-squared: 0.2728
F-statistic: 9.8405 on 7 and 158 DF, p-value: 0.0000000008403

Table 12: *Short-term Dynamics - Do Raw Prices Lead Tinned Prices?*

$$\Delta Price_{Raw_t} = ErrorCorrectionTerm + \sum_{i=1}^{2} \mathrm{B}_i \Delta Price_{Raw_{(t-i)}} + \sum_{i=1}^{2} \mathrm{B}_i \Delta Price_{Tinned_{(t-i)}}$$

Variables	Estimate	Standard Error	t value	p-value	
Long-term Error Correction Term	0.348	0.110	3.162	0.002	***
Break Point Pre 2013	-0.014	0.034	-0.420	0.675	
Break Point 2013 2016	-0.035	0.035	-1.012	0.313	
Tinned Prices - Lag 1	-0.353	0.122	-2.887	0.004	***
Raw Prices - Lag 1	-0.276	0.111	-2.494	0.014	**
Tinned Prices - Lag 2	0.051	0.111	0.457	0.648	
Raw Prices - Lag 2	-0.195	0.089	-2.179	0.031	**

Signif. codes: 0 <= '***' < 0.01 < '**' < 0.05 < '*' < 0.1
Residual standard error: 0.1947 on 158 degrees of freedom
Multiple R-squared: 0.3516, Adjusted R-squared: 0.3229
F-statistic: 12.2408 on 7 and 158 DF, p-value: 0.000000000003996

Tables **11** and **12** represent the short-term price dynamic components of the cointegrating ECM. They capture how each price changes relative to its short-term departure from long-run equilibrium, its previous lagged values, and lagged values of the other prices. For both world raw and tinned tuna prices, the “long-run” each can be in “disequilibrium” is two months. *Both* series move quickly back to equilibrium if shocked.

These price metrics are world prices, but the adjusted R-squared statistics for both VARs suggest this simple short term dynamic model explains approximately 30% of the observed variation in raw and tinned tuna’s price. Other factors affecting price will include input cost changes, and changes in demand conditions in either market. But still, 30% is a significant proportion of each price’s variation that is accounted by market integration between two separate world product markets.

Introducing another protein source, like chicken, might test the robustness of the 30% price variation derived from the raw and tinned market integrations. However, the multivariate model would weaken through loss of the degrees-of-freedom. This is “the curse of dimensionality”.

Tinned price short term dynamics

In Table **11**, the ECT has the highest t-value: being out of price equilibrium with world raw tuna prices is the largest statistic effect changing tinned tuna prices in the short-run. The t-values for lagged raw tuna prices also suggest they are a statistically significant combined source of short-term tinned tuna price variation.

The signs on the raw price lagged variables suggest tinned prices change opposite to how raw prices change. If raw prices increase, tinned prices quickly fall, which is a counter-intuitive result for an input-output relationship. Raw tuna input costs would be expected to pass directly through into increased tinned prices and have positive-signed point estimates in Table **11**.

The negative signed raw price lagged variables might be an artifact of inventory lag. If tinned producers are selling product processed from raw fish bought 3-6 months ago at a different price point, the current month-on-month correlation might appear negative during raw market price volatility.[10]

Potentially tinned producers might also be absorbing short-term price shocks by maintaining tinned price stability. The discussion section suggests that this absorption behaviour might be a consequence of the global vertically integrated structure described in (Jiménez-Toribio, Guillotreau, and Mongruel, 2010).

Returning to the long-run equilibrium, described in Table **9**, is exceptionally quick. From Table **11**, 31% of tinned tuna price disequilibrium is corrected within the first month of a shock moving either price from equilibrium, timing the series complete adjustment to disequilibrium as three months.

Raw price short term dynamics

In Table **12**, the ECT also has the largest statistical effect on short-term raw price dynamics, judged by its t-value. Only the first lag of tinned prices significantly affects short-term raw tuna prices and again has a counter-intuitive opposite-signed direction: if tinned prices increase, raw prices will fall the following month. The second month lagged tinned price is a statistically insignificant factor affecting raw price changes, suggesting tinned prices have a very short duration impact on raw price changes.

Like Table **11**, only 35% of a disequilibrium shock is corrected by raw tuna price adjustment through the ECT relationship in a month, again timing the series complete adjustment to disequilibrium as approximately three months.

[10] Thanks Google Gemini for this helpful suggestion.

A three-month adjustment term is quick, but similar speeds were also found in the literature. For example, (Huang and Leung, 2011) using semi-monthly data producing two observations a month, found a lag length of 6 was appropriate for modelling the integrated Hawaiian and Japanese bigeye markets, implying also a three month disequilibrium adjustment period.

Discussion

Both the raw tuna and tinned tuna markets transmit price signals into the other. Raw tuna price changes are *fully reflected* in tinned tuna changes, and *vice versa* according to bi-directional LOP. Any attempt by tinned tuna producers to permanently separate their product prices from changes in raw tuna input prices will only deliver short-term price separation. Competition will *quickly* enter the market to return the tinned prices back to their long-term relationship with raw prices.

If raw fish prices rise or fall by 10%, tinned tuna producers will need to raise their prices immediately to survive or lower their prices immediately to compete: LOP binds the two complementary product markets. And by “quickly”, the timeframe is two months before tinned prices return to their relationship with raw prices.

Three economic implications therefore follow:

1. “Breaking the Law” of One Price

Successful strategies to achieve a permanent price lift will completely depend on “breaking the Law” of One Price to reduce the sensitivity of tinned prices to raw price shocks.

LOP might be broken if producers can strengthen the marketing of the tinned product by doing one or both of the following strategies. One is about making the product “relatively different”, while the other is about making the product “absolutely different”.

1. Differentiate their product from generic competitor products of the same input product type

If a producer can make their product "different" from their competitors, then the competition aspects which bind raw prices to tinned prices will not force the differentiated product back to the competitive market price. If tinned producers can accentuate *relative* differences between their and competitors' generic tinned tuna products in the minds of the consumers, then LOP's input/output price couplings will be less binding.

The differentiated product will still move proportionally by LOP, but it will maintain a higher margin compared to non-differentiated products. Successfully "differentiated"[11] products could weather raw price changes because competitive pressures with generic products are less. For example, marketing tinned tuna product as "100% domestically produced, sustainably caught, premium quality, locally canned and family owned"[12] and using the implicit negative to refer to "other" products (aka competitors).

2. In consumers' minds, lose the connection between the tinned product and its tuna input source

This is different from the above point where the product is clearly tuna. This aspect means making the tinned product something that is "not tuna" so the connection between the raw inputs and the output product is broken. If successful, producers have more control over their margin through decoupling the price elasticity between the raw tuna inputs and the tinned tuna output products.

[11] Differentiated is quoted because it only needs to be apparently different in the minds of the consumer.

[12] https://littletuna.com.au

Van Camp Seafoods brands a line of their seafood products as “Chicken of the Sea”.[13] While initially being tuna-based, the company has expanded its tinned meats to include salmon, sardines, mackerel, oysters, crab, clams and shrimp under the same brand name.[14] The strategic use of a brand name to *not* signify the products’ meat might actually be a successful marketing strategy for breaking LOP between integrated markets. Van Camp Seafoods can substitute different raw inputs (like salmon or mackerel) without changing the final product’s shelf identity. By making the tinned product a “branded asset” rather than a “processed commodity” Van Camp Seafoods reduce the elasticity of the input price’s transmission, even if the underlying physical relationship between raw and tinned products remains.

Secondly, tinned tuna might not be for humans - its cat food or ‘scientifically balanced holistic’ dog food.[15]

Thirdly, through diluting the quantity of tuna in the product - not deceptively but explicitly - then LOP will only bind a fraction of the product’s input costs. For example, “John West Protein+ Calcium Rich Tuna Tomato & Onion”[16] has less than half its weight as skipjack tuna (46%). The remaining volume is tomato & onion (42%), water, and tuna bone powder [source of calcium] (fish) (4%). Consequently, input price shocks from the raw tuna market will only affect 46% of the raw input costs of John West’s tinned product.

[13] https://chickenofthesea.com/company/

[14] https://chickenofthesea.com/products/

[15] https://www.habitatpets.com.au/products/hills-cat-adult-tuna-156g-x-24, https://www.lifewisepetfood.com/product/wild-tuna

[16] https://johnwest.com.au/product/john-west-protein-calcium-rich-tuna-tomato--onion-90g/12771

2. Raw/Tinned tuna industry market structure derives from LOP and raw tuna price-leadership

With tightly integrated raw and tinned tuna markets, any external factor which affects raw tuna prices will affect tinned prices, and vice versa. Price transmission happens in both direction. If raw tuna prices fall, they will transmit their changes into *permanent* tinned tuna price declines. If tinned prices increase, the cost of raw tuna will be bid up to match through competitive forces. In the long-run, if tinned producers want to increase prices the raw tuna market fundamentals must be directly addressed. And it raw tuna fishers want to increase their prices, the tinned tuna market prices must permanently increase.

In their paper, (Jiménez-Toribio, Guillotreau, and Mongruel, 2010) viewed the raw and tinned tuna markets as non-competitive, vertically integrated and oligopsonistic but struggled to convincingly identify reasons other than trade-based economic distortions that created the international market distortions. Their paper lacked a tangible “smoking gun” explanation for what real or policy-induced barriers-to-entry existed in the global raw and tuna markets that produced a non-competitive, vertically integrated industry as its natural long-run equilibrium economic outcome.

The answer might just be through the implications of LOP - a competitive market theory - and the consequence of tight market integration and more variable price shocks transmitted from the raw market and into the tinned market. Vertical integration between the two world markets might be a natural consequence of the more valuable tinned market receiving more variable price-shocks then the tinned market transmits into the less valuable raw market. Tinned producers seeking to control raw production processes might be their strategy for minimising the risk to thier more valuable market from more intensive price shocks they receive from raw tuna providers.

Tinned tuna is the higher valued of the two markets, seen in Figure **2**. With more value at stake in the tinned market, control of the raw market to control raw-market-derived price shocks naturally follows.

Secondly, in their paper, Jiménez-Toribio, Guillotreau, and Mongruel wrote:

> *Granger causality is traditionally interpreted to suggest that the market side facing the greatest level of uncertainty is likely to produce the exogenous price (Schroeter and Azzam, 1991). In the fishing industry, supply is the natural candidate for such uncertainty but in the case of tuna, the variability of demand, subject to many substitute products and other external shocks could fulfil the role. For instance, the media coverage of the dolphin mortality associated with tuna fishing and the trade restrictions which followed made the US canned tuna consumption fall from 1990, but then the American market recovered after the implementation of dolphin-safe labelling initiatives (Teisl et al., 2002).*
>
> – (Jiménez-Toribio, Guillotreau, and Mongruel, 2010) page 170

In light of this paper's finding, Jiménez-Toribio, Guillotreau, and Mongruel's interpretation of the "market side facing the greatest level of uncertainty" might be wrong.

The "market side facing the greatest level of uncertainty" is the tinned market from more variable price shocks transmitted into it from the raw tuna market. As seen in Figure **2**, the price *variance* in the raw market is significantly higher than in the tinned market, meaning the raw product input cost shocks are more frequent.

Thirdly, Jiménez-Toribio, Guillotreau, and Mongruel's interpretation of the 1990's dolphin scandal is similarly wrong. Tinned producers focused their marketing efforts on emphasising how the *raw tuna* inputs are "sustainably-sourced" and "ethically caught": they deliberately target consumer perceptions about the *raw side of the market* in order to recover value in the *tinned side* of the market.

3. Policymakers seeking change need to address productive economic fundamentals

Finally, the results suggest tuna species conservation needs to focus back onto economic factors and the rules regarding raw tuna harvesting and production. Rather than focus on compensating fishers for lost income or some other indirect focus, substitutability of species and relative cost of production differentials will determine which species is harvested for tinning.

There are two major longline fisheries targeting different species. The southern longline targets albacore, while the tropical longline fishery targets yellowfin and bigeye. Species with higher costs of production, derived from this type of fishing, are almost guaranteed to stay out of a can.

If skipjack, which makes up the bulk of the cheap tuna, was to be protected, increasing its per kilogramme price could be an effective way to dampen its demand. Price increases would pass quickly and directly into the tinned market, where the international quantity of tinned tuna produced would decrease according to tinned-tuna's own price demand elasticity.

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Appendices

Harmonised Commodity Description and Coding "Raw Tuna" and "Canned Tuna" Codes

Table 13: *Raw Tuna HS Codes*

Species	Code	Description
Albacore	030231	030231 - Fish; fresh or chilled, albacore or longfinned tunas (Thunnus alalunga), excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0302.91 to 0302.99
	030341	030341 - Fish; frozen, albacore or longfinned tunas (Thunnus alalunga), excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0303.91 to 0303.99
Bigeye	030234	030234 - Fish; fresh or chilled, bigeye tunas (Thunnus obesus), excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0302.91 to 0302.99
	030344	030344 - Fish; frozen, bigeye tunas (Thunnus obesus), excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0303.91 to 0303.99
Bluefin	030194	030194 - Fish; live, Atlantic and Pacific bluefin tunas (Thunnus thynnus, Thunnus orientalis)
	030195	030195 - Fish; live, southern bluefin tunas (Thunnus maccoyii)
	030235	030235 - Fish; fresh or chilled, Atlantic and Pacific bluefin tunas (Thunnus thynnus, Thunnus orientalis), excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0302.91 to 0302.99
	030236	030236 - Fish; fresh or chilled, southern bluefin tunas (Thunnus maccoyii), excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0302.91 to 0302.99
	030345	030345 - Fish; frozen, Atlantic and Pacific bluefin tunas (Thunnus thynnus, Thunnus orientalis), excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0303.91 to 0303.99
	030346	030346 - Fish; frozen, southern bluefin tunas (Thunnus maccoyii), excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0303.91 to 0303.99
Skipjack	030233	030233 - Fish; fresh or chilled, skipjack tuna (stripe-bellied bonito) (Katsuwonus pelamis), excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0302.91 to 0302.99
	030343	030343 - Fish; frozen, skipjack tuna (stripe-bellied bonito) (Katsuwonus pelamis), excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0303.91 to 0303.99
	030487	030487 - Fish fillets; frozen, tunas (of the genus Thunnus), skipjack tuna (stripe-bellied bonito) (Katsuwonus pelamis)
Tuna NEC	030239	030239 - Fish; fresh or chilled, tuna, n.e.c. in item no. 0302.3, excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0302.91 to 0302.99
	030349	030349 - Fish; frozen, tuna, n.e.c. in item no. 0303.4, excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0303.91 to 0303.99
Yellowfin	030232	030232 - Fish; fresh or chilled, yellowfin tunas (Thunnus albacares), excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0302.91 to 0302.99
	030342	030342 - Fish; frozen, yellowfin tunas (Thunnus albacares), excluding fillets, fish meat of 0304, and edible fish offal of subheadings 0303.91 to 0303.99

Table 14: *Tinned Tuna HSC Codes*

Code	Description
160414	160414 - Fish preparations; tunas, skipjack tuna and bonito (Sarda spp.), prepared or preserved, whole or in pieces (but not minced)

Figure 1- World Tuna Quantities & Values

Click here to access/download;Figure;World_Tuna_Export_Raw_Tinned_Valu

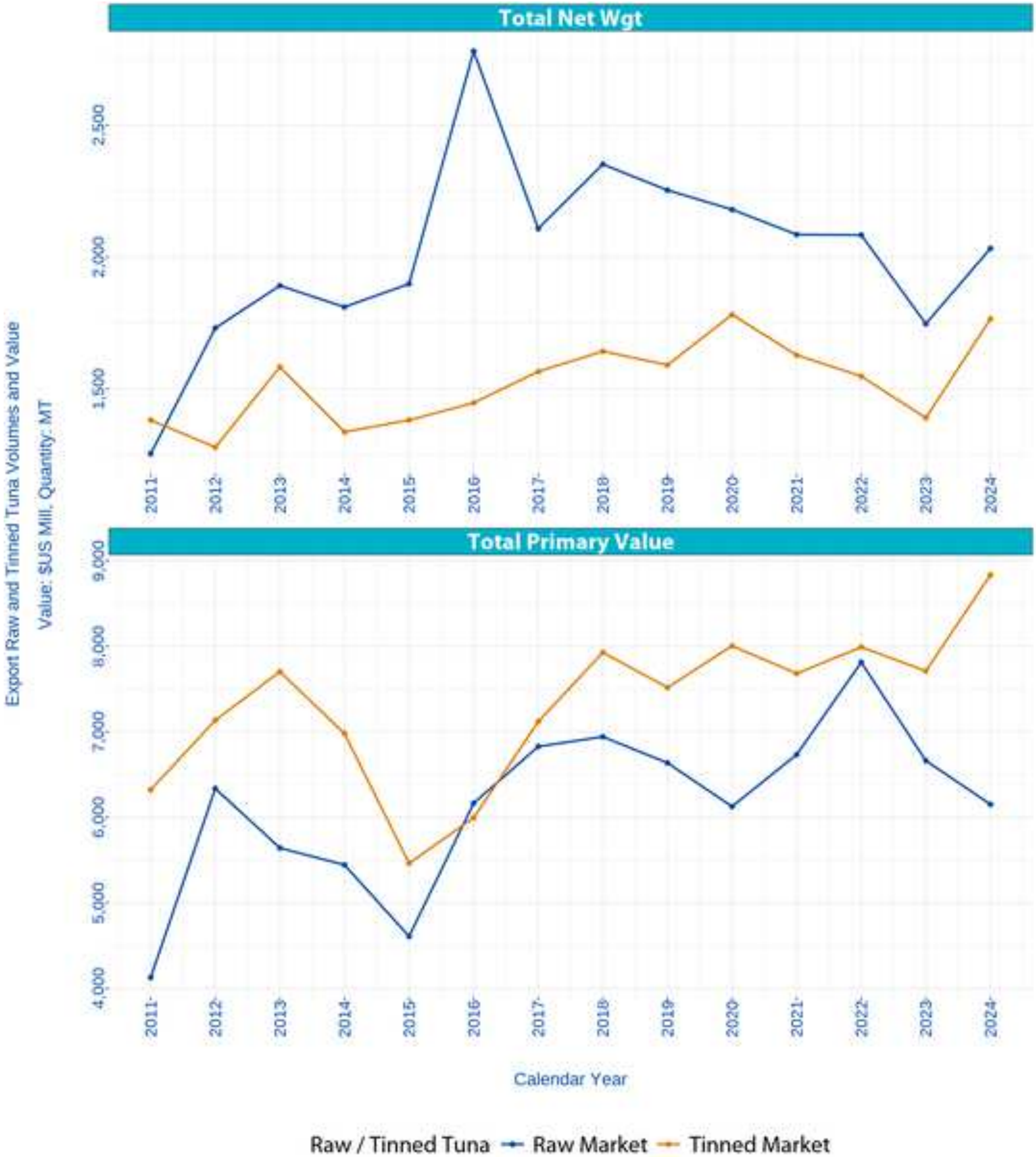


Figure 2: World Export Prices and Quantities - Logarithmic Scale

Click here to access/download;Figure;World_Tuna_Export_Prices_and_Volum

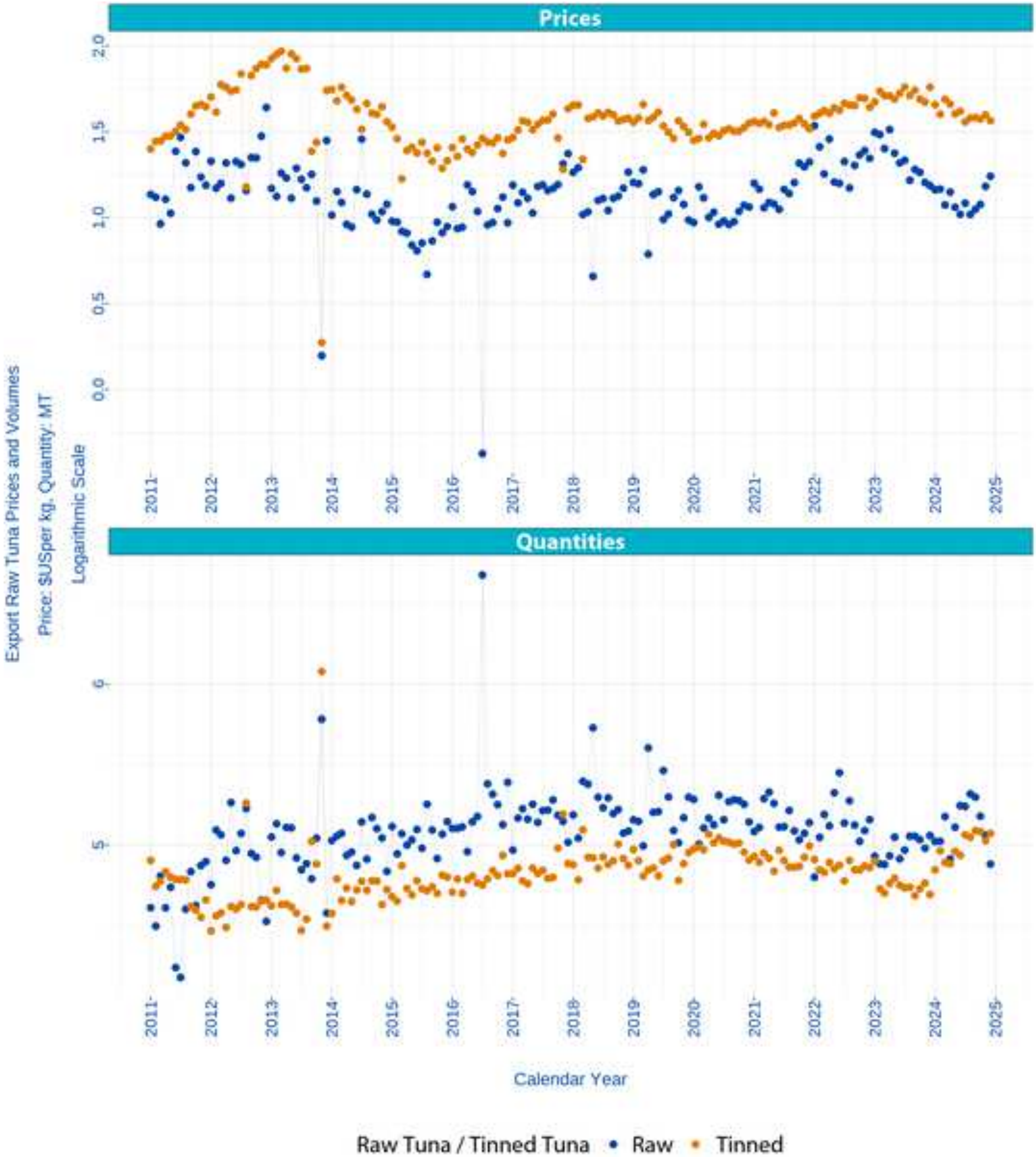


Figure 3: Raw Tuna Price Deciles - All Species

Click here to access/download;Figure;Raw_Tuna_All Species_PaperVersion.png

Figure 4: Tinned Tuna Price Deciles

Click here to access/download;Figure;Canned_Tuna_All Species_PaperVersion.png

Figure 5: Raw Tuna Exports and Imports: 2024 Click here to access/download;Figure;Raw_Tuna_Sankey2024.png

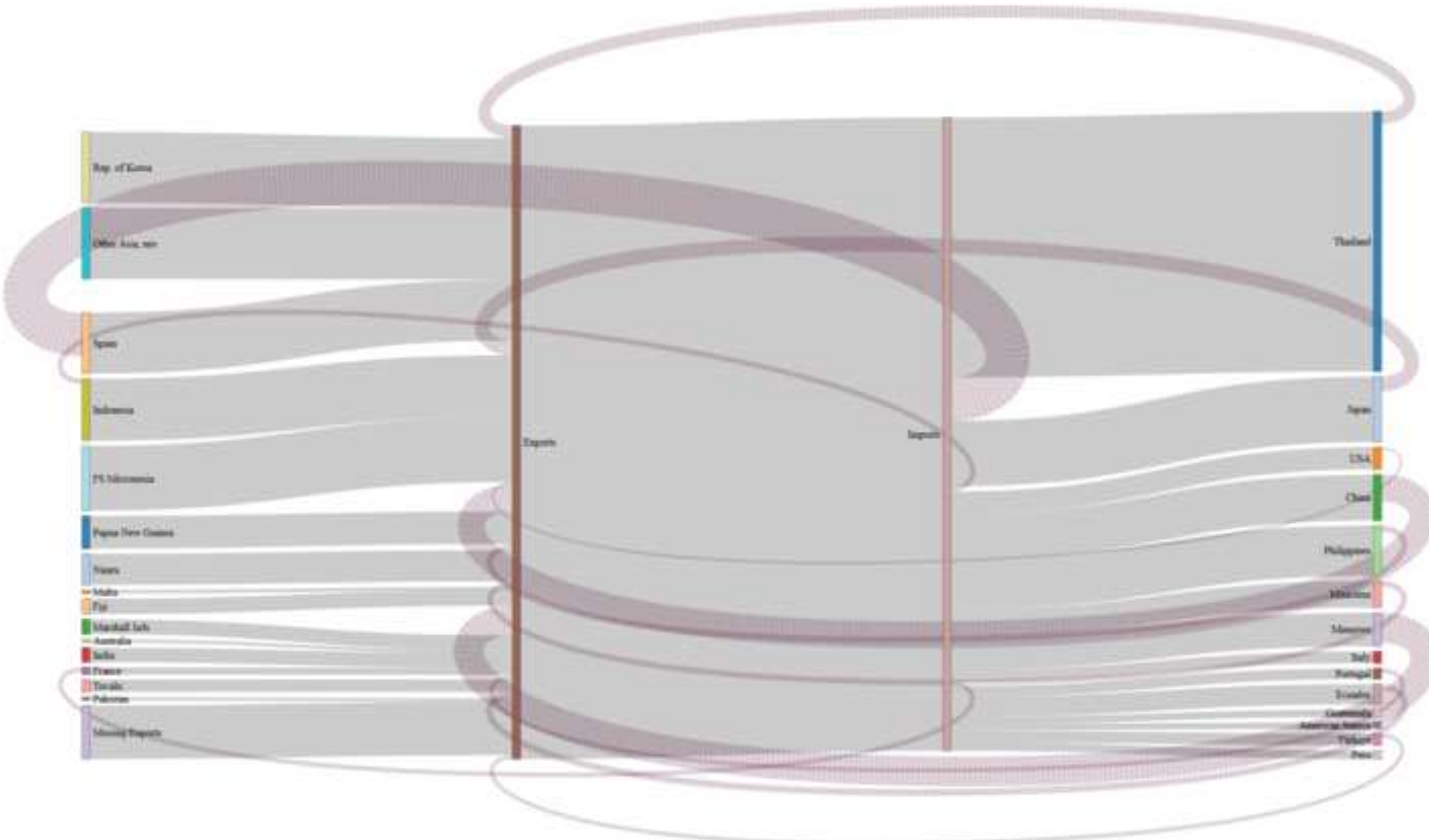
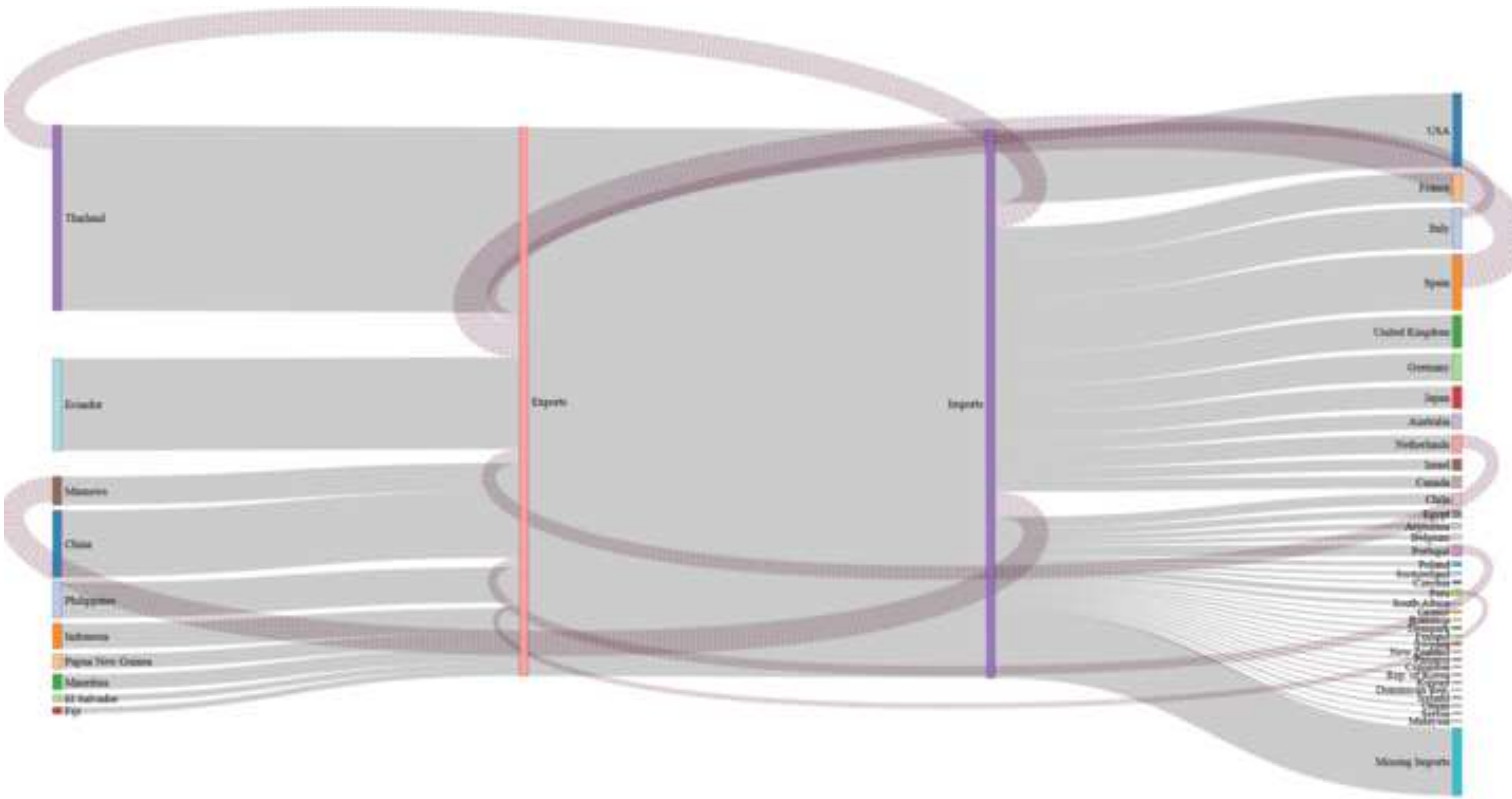


Figure 6: Canned Tuna Exports and Imports: 2024

Click here to access/download;Figure;Canned_Tuna_Sankey2024.png



Declaration of interests

☐The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

This work was written as part of my employed role at the Pacific Community. No other funding or support was received. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.