Are US Wild Salmon Products Affected by Farmed Salmon? A Cointegration Analysis

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ABSTRACT

This paper investigates the degree of market integration between several product forms of US wild salmon and Norwegian farmed salmon. While several studies have investigated the link between farmed salmon and fresh and/or frozen wild salmon markets, we expand the literature with the inclusion of the products canned salmon and salmon roe. Understanding how canned salmon and salmon roe are related to the broader salmon market is of importance to US fisheries, as these products are high-price exports for the United States. Our results find evidence of cointegration between the Norwegian farmed salmon market and all US salmon products. Domestic and international economic conditions, such as production technological advances within farmed salmon production, environmental challenges, and changes in trade regulations, which affect the market for farmed salmon, will hence also influence US prices of frozen and canned salmon, as well as salmon roe.

Key words: Aquaculture, cointegration, fish markets, international trade, salmon.
JEL codes: D40, Q22.

INTRODUCTION

The fact that there is a global market for salmon has been indicated by several studies, starting with that of Asche, Bremnes, and Wessells (1999), who found that the global market for salmon compromised several salmon species (chum, sockeye, pink, coho, and Atlantic salmon) and product forms (fresh and frozen), and that the prices of farmed Atlantic salmon determine the price of all species of Pacific salmon. Asche (2001) found that the three main markets for Atlantic salmon—the EU, Japan, and the US—are highly integrated, but that the link between the US salmon market and the European and the Asian markets is weaker than the link between the European and the Asian markets. In the Japanese market, which used to be the largest and most diversified salmon market in the world, Asche et al. (2005) found that farmed salmon trout, wild-caught sockeye, and wild and farmed coho are close substitutes, with the law of one price (LOP) holding, and that the expansion of imported farmed salmon has resulted in a price

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decrease for all salmon species. Likewise, in Finland, imported fresh farmed Atlantic salmon, domestic wild-caught salmon, and farmed salmon trout were found to be close substitutes, with the farmed Atlantic salmon the price leader (Mickwitz 1996; Virtanen et al. 2005). In the German trout market, Nielsen et al. (2007) found that the market for farmed frozen Atlantic salmon was fully integrated with farmed frozen trout, and Landazuri-Tveteraas et al. (2021) show a similar result for Norwegian exports.[1] Asche, Cojocaru, and Sikveland (2018) found a highly integrated market for four Chilean product forms of farmed Atlantic salmon (fresh and frozen fillet, and fresh and frozen whole), and, as the LOP held relative to Norwegian farmed salmon, they concluded that all are well integrated into the global market. Landazuri-Tveteraas et al. (2018) investigated the extent of price transmission within the salmon supply chain, using the export price of fresh salmon from Norway and retail prices for a variety of salmon products in France and the United Kingdom, and found price causality from export to retail level, and that price transmission was complete for unprocessed products but not for processed products. Recently, Salazar and Dresdner (2021) show that salmon from the main producer countries is fully integrated in the US market.

While previous studies uniformly conclude that a global market for salmon exists, they provide only a partial picture of US salmon production, because of the limited focus on frozen and fresh salmon. To our knowledge, no study has investigated how canned salmon and salmon roe relate to the larger salmon market. Very little farmed salmon is canned, and there is an understanding that canned salmon has faced relatively little competition from farmed salmon (Knapp, Roheim, and Anderson 2007). While this most likely is true in the retail market, in Alaska, fishers have a choice with respect to which buyers they sell their fish to, and if the ex-vessel market is reasonably efficient, one would expect the price of salmon going to canning to have the same trends over time as the fish that is frozen. While this is the case in many areas, in some remote areas, salmon producers have very few options regarding which processor they use. However, the processing industry also has a choice with respect to which products are produced, and one would expect the price of salmon going to canning to have some connection over time to frozen salmon prices. Understanding how canned salmon is related to the rest of the salmon market is, however, of particular importance to the US salmon market, since more than two-fifths of US wild salmon have traditionally been sold as canned, and canned salmon accounts for up to 38% of the US salmon export value.

Salmon roe markets are presumed to be affected by different factors than those affecting markets for salmon flesh products (canned, frozen, and fresh salmon) and exhibit different trends over time (Knapp, Roheim, and Anderson 2007). Because the quality of the roe is inversely proportional to that of the flesh, most farmed salmon are harvested well before they start to mature sexually,[2] and, currently, very little salmon roe is sourced from farmed salmon. Also, for the fishermen, it is a trade-off between the quality of the flesh and the occurrence of roe.[3] This means that the salmon roe market has not been exposed to competition from farmed salmon in the same way

1. Several studies have investigated the cointegration between salmon and other species. Salmon constitutes a different market with a separate price determination process from all species but large trout. Bjørndal and Guillen (2016) provide an excellent review of this literature.

2. Although most of the world's salmon roe production is from wild salmon, roe produced from Scandinavian farmed trout is of high quality and could have significant effects on future roe markets.

3. "Roe-stripping," where salmon is harvested only for its roe and the salmon carcasses grinded up and dumped at sea, is normally illegal in Alaska. However, in some years, the salmon price has fallen below the costs of processing, and players have been approved to carry out this practice (Knapp, Roheim, and Anderson 2007).

that wild fresh and frozen salmon has. This has allowed wild salmon roe producers to maintain their position in the world market. To our knowledge, the degree that these markets are related (or unrelated) and the extent to which salmon roe and canned salmon are shielded from changes in the world's salmon market have not been investigated.

To address this research gap, we utilize a Johansen cointegration analysis to investigate the relationship between the price of the traditional market leader (Norwegian farmed salmon) and the largest species of US canned and frozen salmon, as well as salmon roe. We utilize monthly data covering the period 1991–2018 and test for market integration, the LOP, and price leadership. As pointed out by Bjørndal and Guillen (2017), results may be sensitive to the period investigated. Results based on older data may have little relevance to the current market conditions, as the earlier period has generally been characterized by increased globalization and transformative changes in fisheries' production, regulations, and consumer demand (Anderson, Asche, and Garlock 2018; Asche and Smith 2018), and fish markets are dynamic and are changing continuously. Throughout the 1991–2018 sample period, one can observe significant changes in markets and products for US wild salmon. During the 1980s and early 1990s, a large share of the US sockeye landings were exported frozen to the Japanese market, but, as the competition from farmed salmon increased over the 1990s, farmed Atlantic salmon took market share from wild salmon, and more and more of the wild US salmon went into canning.[4] In recent years, a higher share of US landed salmon is being sold frozen, domestically (Anderson, Asche, and Knapp 2019), as US consumers appear to be showing stronger preferences for domestically caught wild salmon. By splitting the US export data into different species and product forms, we investigate whether the relationship differs for different species and product forms, and whether these relationships have changed over time.

Our price series is characterized by subperiods that follow increasing and decreasing trends. The first half of our data series, prior to 2002, is characterized by a trend of declining salmon prices, while the second half, post 2002, is characterized by a trend of increasing salmon prices. These trends are observed in both farmed and wild salmon markets and may indicate that the markets are integrated in periods of both decreasing and increasing prices. However, only a limited number of market integration studies have been conducted using observations from the post-2002 period. Asche, Cojocaru, and Sikveland (2018) used the Johansen approach on monthly unit prices from Chilean and Norwegian exports, for the period January 2002 to December 2015, and found a highly integrated market for all four Chilean product forms investigated, and that these are all well integrated into the global market. Valderrama and Anderson (2008) used a regulated open-access model to uncover the underlying regulated open-access characteristics of the drift gillnet salmon fishery in Bristol Bay from 1980 to 2006, revealing that differences in productivity growth define the nature of market integrations between the salmon aquaculture and fisheries sectors.[5] By utilizing data for the period 1991–2018, we are able to investigate whether salmon markets are cointegrated, in periods of both decreasing and increasing prices. To test whether the market connections are different in times of increasing and decreasing markets, we estimate the models on subsets of the data, and test whether the LOP and weak exogeneity hold in both periods.

4. Further, over this period, Japanese imports of Russian salmon also increased.

5. Valderrama and Anderson (2008) are, however, not utilizing the standard cointegrating estimation techniques to confirm this hypothesis.

The rest of this paper is specified as follows: the next section describes the development of the international salmon industry. We then give a brief summary of the methodology used to investigate the relationship between the markets and provide a description of the data used in the analysis. The section thereafter presents our results, before we provide concluding remarks.

THE SALMON MARKET

The world production of both farmed and wild-caught salmon has increased from about 500,000 tons in 1980 to approximately 3,600,000 tons in 2017. Over this period, the means of salmon production has flipped from primarily wild capture (98%) in 1980 to majority farmed salmon aquaculture (75%) in 2017. Thus, while wild-capture fisheries have seen landings increase by roughly 84%, farmed salmon production has increased by 26,000% over the same time (FAO 2019). Production of farmed Atlantic salmon is concentrated, with Norway leading production, accounting for roughly 55% of world production. Norway is followed by Chile, the second-biggest producer, with roughly 23.5% of farmed Atlantic salmon production, with the UK (Scotland) close to 8%, Canada around 5.5%, and the Faroe Islands with just over 3.5%. Russia and the United States are the largest wild salmon producers. Combined wild salmon harvests in Russia and the United States totaled around 921,000 tons in 2018, with the Russian Kamchatka Peninsula fishery accounting for 70% of this total. In Alaska, catches were around 275,000 tons. Sockeye salmon made up the largest proportion of the US landings, with a 43% share (FAO 2019).

From the early 1980s to the turn of the century, the increase in production was accompanied by a declining real price. Asche et al. (2005) argue that, as the production of farmed salmon expanded, the increased supply of salmon pushed prices for both farmed and wild salmon down.[6] This was profitable for the Norwegian producers of farmed salmon, since productivity growth and scale economics lowered production costs while expanding total output, and the producers managed to maintain profit margins over the years (Asche, Roll, and Tveterås 2009; Asche, Guttormsen, and Nielsen 2013; Roll 2013; Vassdal and Holst 2011).[7] On the other hand, for the wild salmon fishery, the decreased price had a hampering effect. Knapp, Roheim, and Anderson (2007) and Valderrama and Anderson (2008, 2010) found that the falling Alaskan ex-vessel price led to declining profit margins and reduced participation in the limited-entry fishery.[8]

As illustrated in figure 6A, the real salmon price reached its lowest point in the early 2000s and has since shown an increasing trend. There are many potential reasons for this. First, demand growth has been larger than supply growth (Asche et al. 2011; Brækkan et al. 2018). On the demand side, global demand for salmon has been increasing. Demand growth in both geographical and product space as well as more efficient logistics have been important for the massive growth in salmon demand over the last decades (Asche, Roll, and Tveterås 2007; Asche 2008; Cojocaru, Iversen, and Tveterås 2021). On the supply side, Chile, the world's second-biggest producer of

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6. For consumers, this means reduced product prices, as the lower prices have been passed on to them (Asche 2008). Furthermore, as pointed out by Valderrama and Anderson (2008), the growth in the aquaculture sector has contributed to the promotion of seafood consumption and the development of new markets: for both salmon species and seafood in general.

7. There seem, however, to be substantial cycles in profitability around a long-term trend (Andersen, Roll, and Tveterås 2008; Oglend and Sikveland 2008).

8. As pointed out by Knapp, Roheim, and Anderson (2007) and Valderrama and Anderson (2008), external shocks may have influenced the relationship between markets and influenced prices downward; two examples of external shocks are the *Exxon Valdez* oil spill, which decreased production of US Alaskan wild salmon, and the recession of the Japanese economy through the 1990s. Nevertheless, most industry experts agree that the decline in wild salmon price over the 1980s and 1990s is in part due to the influx of farmed salmon.

famed salmon, experienced a decrease in production during this period due to environmental issues (Asche, Cojocaru, and Sikveland 2018). Second, as the farmed salmon industry has moved into a more mature stage, it has entered a period of limited productivity growth (Asche, Guttormsen, and Nielsen 2013). As pointed out by Asche et al. (2011), as the industry matures, there appears to be less scope for technological innovations to increase productivity. Over the last decades, as the industry has matured, it has become more dependent upon external factors, such as demand and regulation, over which it has less control (Asche, Guttormsen, and Nielsen 2013).

Between 80% and 99% of the Norwegian salmon production is exported as fresh or chilled (SSB 2019), while, historically, most US wild salmon landings are either canned or frozen. Traditionally, Japan has been the most important market for US wild salmon (Knapp, Roheim, and Anderson 2007). In the early 2000s, less than 20% of the US landings were sold as fresh or frozen in the domestic market. Since only a small fraction of the US landing is sold domestically, historically, most of the competition between US wild salmon and farmed salmon has occurred in Japan or in the EU, rather than in the US market.

Figures 1 and 2 illustrate the export volume and value of US salmon, separated by product forms. As shown in the figures, while canned salmon makes up the majority of the volume, frozen salmon is the largest contributor to the value. This is due to the relative prices between the product forms. Over time, there have been substantial changes in US wild salmon markets and products. US export volume and value were at record high during the early 1990s, a consequence of high catches and values. Throughout the 1990s, the US frozen salmon export value fell by more than a half, primarily due to a dramatic decline in sockeye landings,[9] as well as increased competition from farmed salmon in important export markets. In part due to diminishing market share in the Japanese frozen sockeye market, a larger portion of the US sockeye landings went into canning. This led to an increase in the volume and value from canned sockeye export through the early 2000s (see figures 1 and 2). However, through the 2010s, this trend subsided, as more US sockeye is now directed into the domestic market.

Since 2002, the US export value has rebounded significantly, mainly because of increased export of frozen pink and chum, as well as higher salmon prices for sockeye (see figures 3 and 7). After 2010, a larger share of the US fresh and frozen salmon was also sold domestically, as US consumer preferences shifted towards domestic wild salmon (Roheim, Sudhakaran, and Durham 2012; Davidson et al. 2012). Aggressive marketing campaigns (e.g., from the Bristol Bay Regional Seafood Development Association) seem to have been important in this respect. Major US retailers like Whole Foods and Costco are avoiding salmon from Chilean farms, and Target did not sell farmed fish for almost a decade.[10]

In contrast to frozen salmon, where the wild salmon industry has been losing market share to farmed salmon, canned wild salmon remains an important product for the wild salmon industry.

9. In terms of value, sockeye has traditionally been the most important species in the United States. In most years, sockeye accounts for over half of the value of US salmon catches (this was a result of both high volumes and prices). The massive decline in sockeye catches dramatically hampered the US salmon industry and has been a significant factor contributing to the economic difficulties of Alaskan salmon fishermen (Knapp, Roheim, and Anderson 2007). It is unclear what caused the decline in sockeye catches, but Knapp, Roheim, and Anderson (2007) point to changes in ocean, stream, and other environmental conditions as likely factors.

10. Recently, Target has changed its policy and is now selling fish from operators certified by the Aquaculture Stewardship Council (2019).

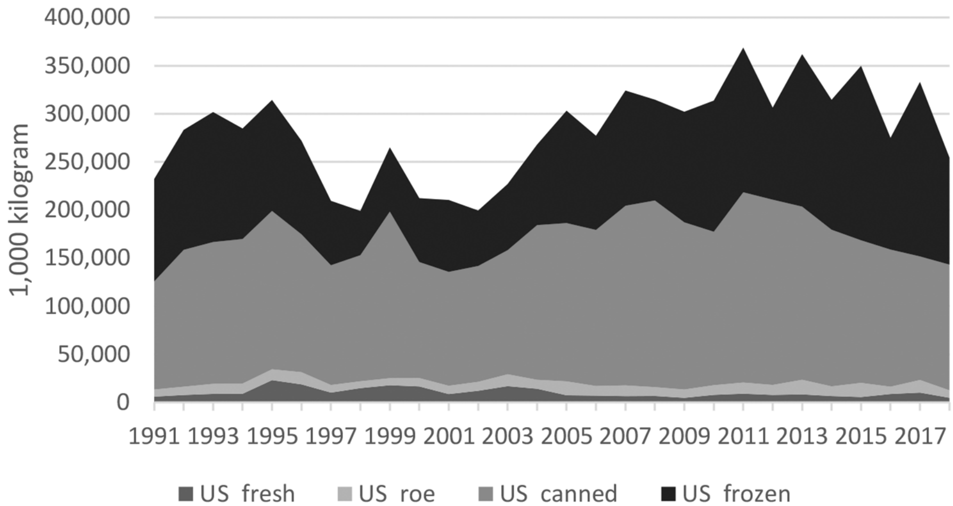

Figure 1. Yearly Volume of US Exports of Salmon Separated by Product Form

The US is the largest producer of canned salmon, followed by Russia and Canada (Knapp, Roheim, and Anderson 2007). Canned salmon is sold into a very different market than frozen salmon, where very little is sold to Japan in canned form. The United Kingdom is the most important market for canned sockeye, while the domestic market is the most important market for US canned pink salmon. Sockeye salmon typically accounts for about two-thirds of the US canned salmon export value, while pink salmon accounts for roughly one-third (figure 4).

As illustrated in figure 1, the volume of US salmon roe production is relatively small, in comparison with that of canned and frozen salmon. However, as illustrated in figure 2, salmon roe is a valuable salmon product—over the sample period, the average value share from roe has been

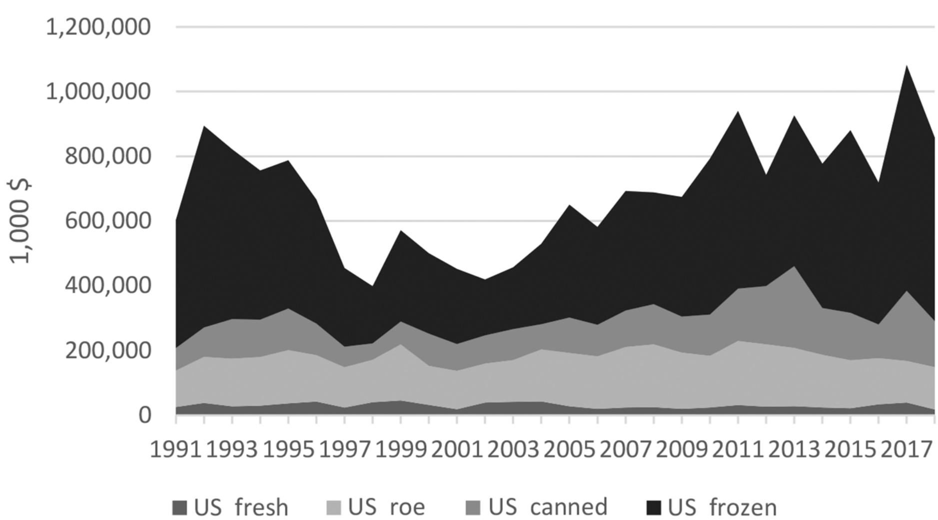

Figure 2. Yearly Value of US Exports of Salmon Separated by Product Form

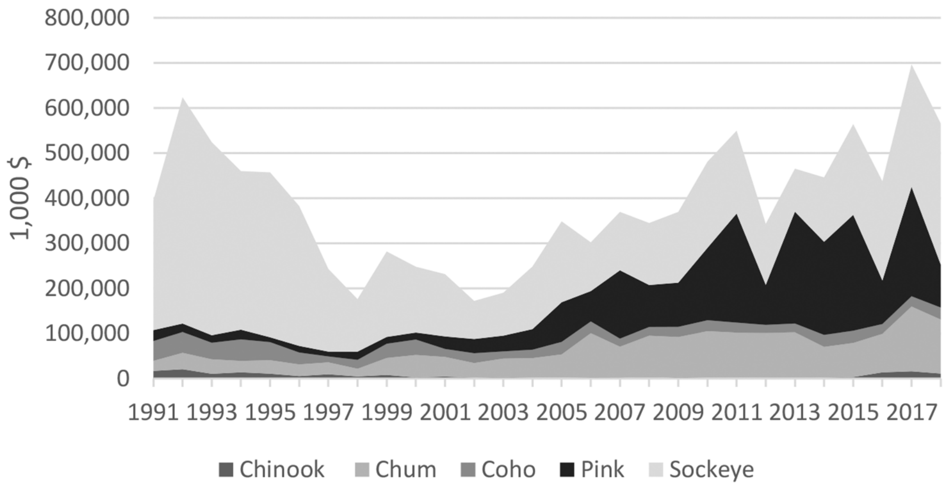

Figure 3. Development of US Export Value of Frozen Salmon Separated by Species

17%, peaking in 2015 at 27% of the value share or $250,000,000. Japan accounts for the largest share of production, followed by the United States and Russia. Almost all US salmon roe production is exported, mostly to Japan, which is the world's largest market, followed by Russia. Very little fresh salmon is exported from the United States (see figure 1). The yearly value share from fresh salmon is between 3% and 12%. Because of fresh salmon's relatively small export value share, it will not be the subject matter of this analysis.

MARKET INTEGRATION

Market integration implies that prices of related goods follow the same long-term pattern because of a common price determination process, and it indicates that there is substitutability between the products. If two products are substitutes, a price change in one market or for one product will

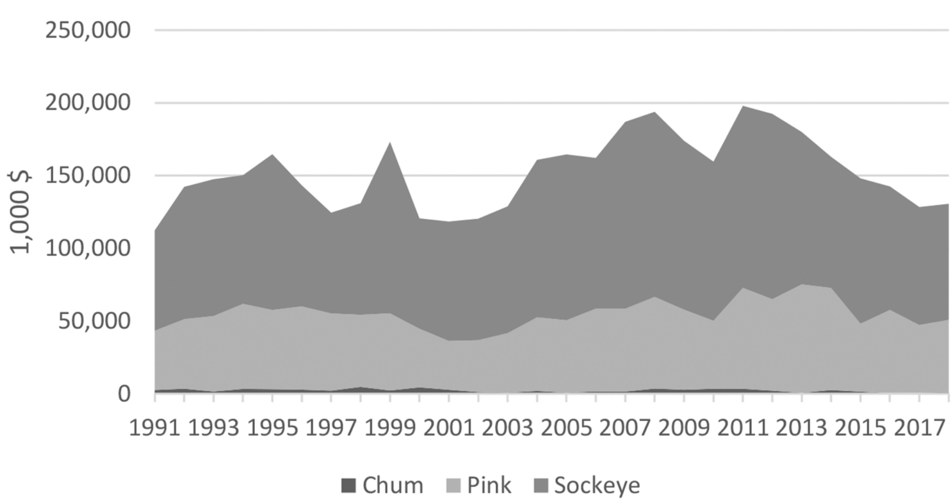

Figure 4. Development of US Export Value of Canned Salmon Separated by Species

lead to a price change in the other; however, if the products are not substitutes, a change in price in one market will not affect the price in the other market.

The basic relationship is given as follows:

$$\ln P_t^1 = \beta_0 + \beta_1 \ln P_t^2 + \varepsilon_t, \tag{1}$$

where P_t^i is the price observed for product i at time t, β_0 is the difference in price level associated with differences in transportation and transaction costs or quality, and ε_t is the error term. The β_1 parameter captures the relationship between the two price series. If $\beta_1 = 0$, there is no relationship between the two price series; if $\beta_1 = 1$, the two markets are fully integrated, which means that the relative price between two products is constant, and the law of one price (LOP) holds. If $0 < \beta_1 < 1$, there is a relationship between prices, but it is not constant, indicating imperfect substitution. If P_t^1 and P_t^2 are nonstationary and integrated of order 1, and a linear combination of them that is stationary exists, then prices are cointegrated. Hence, if P_t^1 and P_t^2 are cointegrated, the error term will be stationary.[11]

To investigate market integration, cointegration analysis is the primary tool. Most recent market integration studies employ the Johansen cointegration test (Johansen 1988), which is based on the vector error correction (VEC) model, where the equation is differenced and an error correction term measuring the previous period's deviation from long-term equilibrium is included. The VEC also takes into account any cointegration relationships among the variables.[12] A two-variable VEC (P^1 and P^2) with s lags can be written as the following:

$$\begin{aligned}\Delta P_t^1 = \beta_{10} &+ \beta_{11t-1}\Delta P_{t-1}^1 + \cdots + \beta_{11t-s}\Delta P_{t-s}^1 + \beta_{12t-1}\Delta P_{t-1}^2 \\ &+ \cdots + \beta_{12t-s}\Delta P_{t-s}^2 - \alpha_1(P_{t-1}^1 - \beta_0 + \beta_1 P_{t-1}^2) + \varepsilon_t^1,\end{aligned} \tag{2}$$

$$\begin{aligned}\Delta P_t^2 = \beta_{20} &+ \beta_{21t-1}\Delta P_{t-1}^1 + \cdots + \beta_{21t-s}\Delta P_{t-s}^1 + \beta_{22t-1}\Delta P_{t-1}^2 \\ &+ \cdots + \beta_{22t-s}\Delta P_{t-s}^2 - \alpha_2(P_{t-1}^2 - \beta_0 + \beta_1 P_{t-1}^1) + \varepsilon_t^2,\end{aligned} \tag{3}$$

where $P_t^1 = \beta_0 + \beta_1 P_t^2$ is the long-term cointegrating relationship between the two variables, and α_1 and α_2 are the error correction parameters (or adjustment parameters) that measure how P^1 and P^2 react to deviations from long-term equilibrium.[13] The number of lags is determined by a number of lag-order selection tests: log likelihood (LL), final prediction error (FPE), Akaike information criterion (AIC), Hannan-Quinn information criterion (HQIC), and Schwartz information criterion (SBIC). To select the number of lags to consider in the model, we perform all tests and use the lag length indicated by the majority of the tests.

The most common test to determine the number of cointegrating relationships among the time series in a VEC is the Johansen cointegration test (Johansen 1995). The number of cointegrating relationships is measured by the cointegrating rank, r. The Johansen trace test for cointegration and the maximum eigenvalue test (max test) are used to test the rank. For the two-variable VEC, if $r = 2$, the prices in levels are stationary. If $r = 0$, then no linear combination of prices is stationary. If $r = 1$, a cointegrating vector (i.e., a stationary linear combination of the price time series) exists.

11. Stationarity indicates that the statistical properties of a process generating a time series are constant over time.

12. Two nonstationary time series are cointegrated if they tend to move together through time.

13. When applying VEC to more than two variables, there is a possibility of more than one cointegrating relationship existing. To allow for more than one cointegration equation, it is necessary to utilize a model that allows multiple error correction terms in each equation. If there are n $I(1)$ variables in a system, there can be up to $n - 1$ cointegrating relationships linking them.

The Johansen procedure allows for a wide range of hypothesis testing on the coefficients α and β, using likelihood ratio tests (Johansen and Juselius 1990). The matrix β represents the long-term relationship in the system. These are of interest with respect to the structural information in the system and particularly for testing the LOP, which requires constant relative prices or that all parameters in each cointegrating vector sum to zero (Asche, Bremnes, and Wessells 1999). Johansen and Juselius (1990) show that any linear restriction on the cointegration vector can be tested using a likelihood ratio test. If a group of goods is to be in the same market, all prices must be pairwise cointegrated. In a system with n prices, there must be $n - 1$ cointegration vectors for there to be only one stochastic trend. Hence, when the system contains two prices, there will be one cointegrating vector if there is market integration. A test of LOP is a test of $\beta = (1, -1)'$.

Formally, the adjustment parameters (α) are related to the concept of weak exogeneity. If all adjustment parameters are zero in one equation, then this variable is weakly exogenous for the long-term parameters, β, in the remaining equations (Johansen and Juselius 1990). This price will then be determined outside the system, and the item will be considered the price leader. However, this implies that the parameter estimates that the levels of the variables in the system are zero in this equation, and that the other variables cannot in the long run cause this variable.

DATA

To test the market integration of salmon, we utilize real price data for Norwegian fresh exports and US canned and frozen exports. The Norwegian price data are based on the Nasdaq Salmon Index and the Mundi salmon price index. The Nasdaq Salmon Index is the weighted average of weekly reported sales prices and corresponding volumes in fresh Atlantic superior salmon, head on gutted (HOG), reported to Nasdaq Commodities by a panel of Norwegian salmon exporters and salmon producers with export licenses. The data series is reported from 1995 until the present. The panel is representative of the total export from Norway, by representing approximately 25% to 30% of the export volume of farmed salmon.[14] The Mundi salmon price index is a monthly index of the export price of farm-bred Norwegian salmon, measured in dollars per kilogram for the period May 1989 to June 2017. The source of the index is the International Monetary Fund (https://www.imf.org/en/Research/commodity-prices). As illustrated in figure 5, the two indexes are strongly correlated, and, in the analysis, we use an average of both datasets for all available dates, and by that extend the period at both ends. While the Nasdaq Salmon Index was reported in euro, all prices were converted into US dollars prior to the analysis. Despite substantial short-term deviations in prices, the figure clearly illustrates that salmon prices have followed a falling trend from the early 1990s until the early 2000s, before turning in 2002 and starting an increasing trend. The figure also illustrates that price volatility was larger in the first half decade and the last decade of the data series. High volatility in the last decade is consistent with the findings of Asche, Misund, and Oglend (2019).

The US price data are based on the monthly US trade statistics (NOAA 2019). The data series includes monthly export, import, and reimport volumes and values of different salmon species and product forms, reported from 1991 to 2018. For the analysis, we utilize the US export

14. In a recent study, Dahl, Oglend, and Yahya (2021) looked at the Fish Pool Index (FPI), which is a weighted average of the Nasdaq index (95%) and Statistics Norway (5%) export prices, to examine the cointegration between FPI and salmon stock prices.

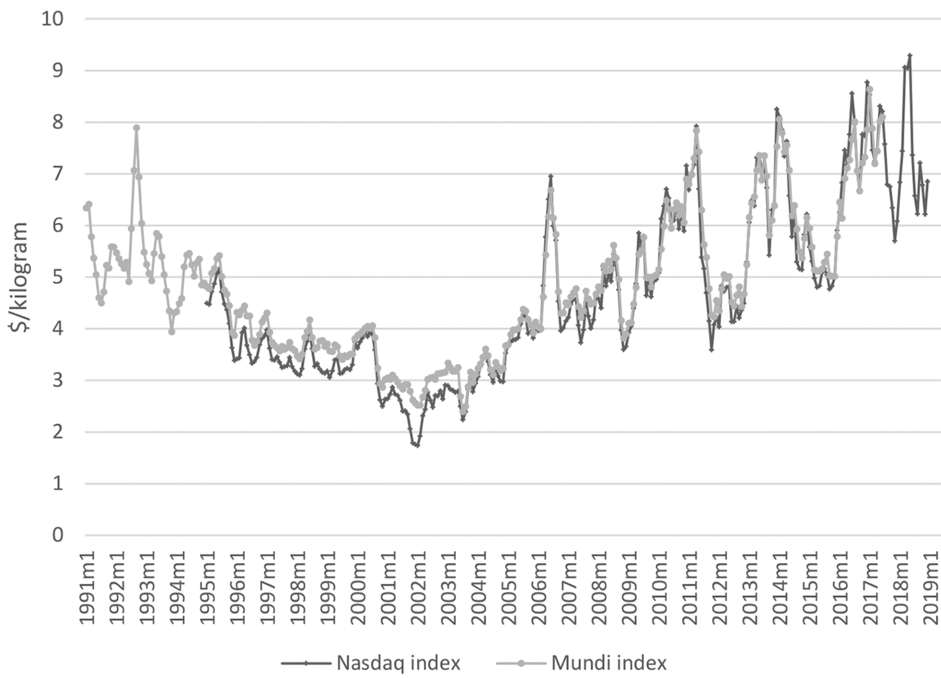

Figure 5. Real Price Series of Norwegian Salmon Price

statistics and focus on the most common US species (chum, pink, and sockeye) and the most common product forms (frozen, canned, and roe).

The price series of Norwegian salmon exports and an aggregate of US fresh, frozen, canned, and roe export salmon prices are illustrated in figure 6A. The price series seem to follow each other moderately. Note, for most of the time series, the Norwegian price index was higher than that of the US price index. In terms of price variation over time, US prices appear to be less volatile relative to Norwegian prices. This is confirmed by the calculated coefficient of variation (CV) reported in table 1, in which the value of CV for Norwegian prices is roughly double that of US prices. Panel B of figure 6 illustrates the first differences of the price series. As can be seen from this figure, these seem to be stationary.

Figure 7 illustrates the price series of Norwegian salmon exports, together with the export price of US frozen sockeye, pink, and chum.[15] The price series for Norwegian salmon and US frozen sockeye seem to follow each other relatively closely but with periods during which they diverge more than at others. On average, the price level is slightly higher for US frozen sockeye, indicating that consumers are willing to pay a premium for wild fish. For the US frozen sockeye price, there also seems to be less variation in prices, compared with the Norwegian export price, which is expected, as frozen salmon can be stored. This is confirmed by the CV reported in table 1. However, the size of the CV is larger in the last period (2003–18), indicating that variation in prices has increased over time. US frozen pink and chum exports have a significantly lower price, and it is harder to spot a relationship with the Norwegian price series from figure 7.

15. Despite yearly landing and US export of also chinook and coho, in this paper, we focus on the three largest US species: sockeye, pink, and chum.

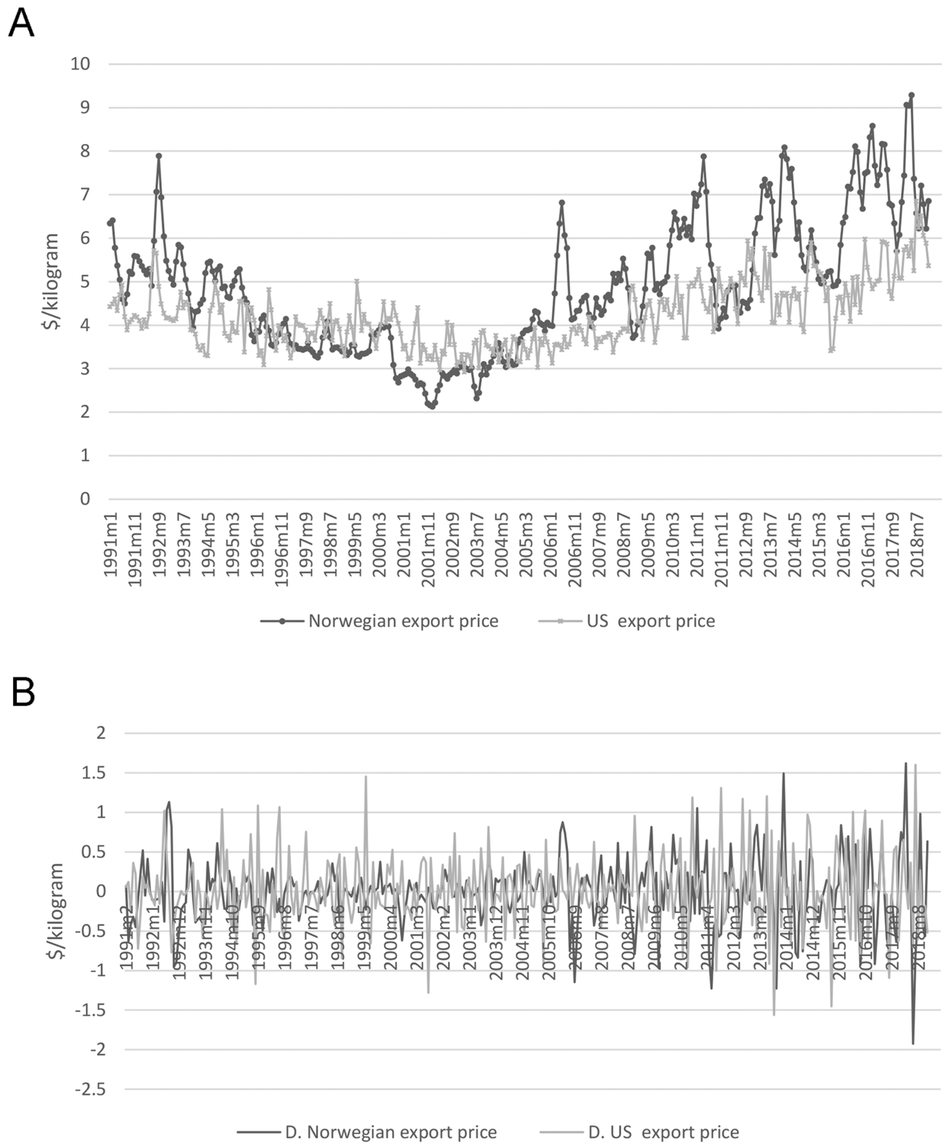

Figure 6. Norwegian and US Real Export Price of Salmon (all species and product forms) in Levels (A) and in First Differences (B)

The difference in price to the Norwegian salmon price seems to have increased since 2010, as the prices of frozen pink and chum seem to have flattened out—possibly indicating that the frozen pink salmon market has not benefited from the price increases observed in the Norwegian salmon market in latter years. Lastly, US frozen pink prices have seen more price variation relative to the Norwegian export price.

Figure 8 shows export prices for Norwegian salmon and US canned sockeye and pink. For the prices of the canned species, it is harder to see a close relationship with the Norwegian export price. Canned sockeye has a significantly higher price than canned pink. The export price of canned sockeye was relatively stable until the middle of 2012, when prices jumped. Canned pink

Table 1. Summary Statistics for All Price Series Measured in $/kg

	1991–2018 (n = 336)			1991–2002 (n = 144)			2003–2018 (n = 192)		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Norwegian ($/kg)	4.836	1.507	0.312	4.101	1.106	0.270	5.387	1.535	0.285
US aggregate ($/kg)	4.213	0.732	0.174	3.978	0.506	0.127	4.389	0.822	0.187
Sockeye frozen ($/kg)	4.959	1.253	0.253	4.479	0.924	0.206	5.319	1.345	0.253
Pink frozen ($/kg)	2.379	0.647	0.272	2.210	0.587	0.266	2.506	0.662	0.264
Chum frozen ($/kg)	2.600	0.427	0.164	2.480	0.391	0.157	2.690	0.432	0.160
Sockeye canned ($/kg)	5.444	1.451	0.266	4.771	0.703	0.147	5.949	1.651	0.277
Pink canned ($/kg)	3.226	0.841	0.261	3.003	0.516	0.172	3.392	0.987	0.291
Salmon roe ($/kg)	11.618	4.294	0.370	10.522	4.682	0.445	12.430	3.786	0.304

price has increased slightly since early 2000, but it has been flat over the last decade. For the first subsample period (1991–2002), the variation in canned salmon prices is significantly less than that of the Norwegian export price. The prices for both US canned sockeye and pink have significantly less variation than the Norwegian price in the subsample period (1991–2002). This is as expected, since canned salmon can be stored to a much greater degree. However, in the second subsample period (2003–18,) the price variation of the US products is similar to that of Norwegian salmon.

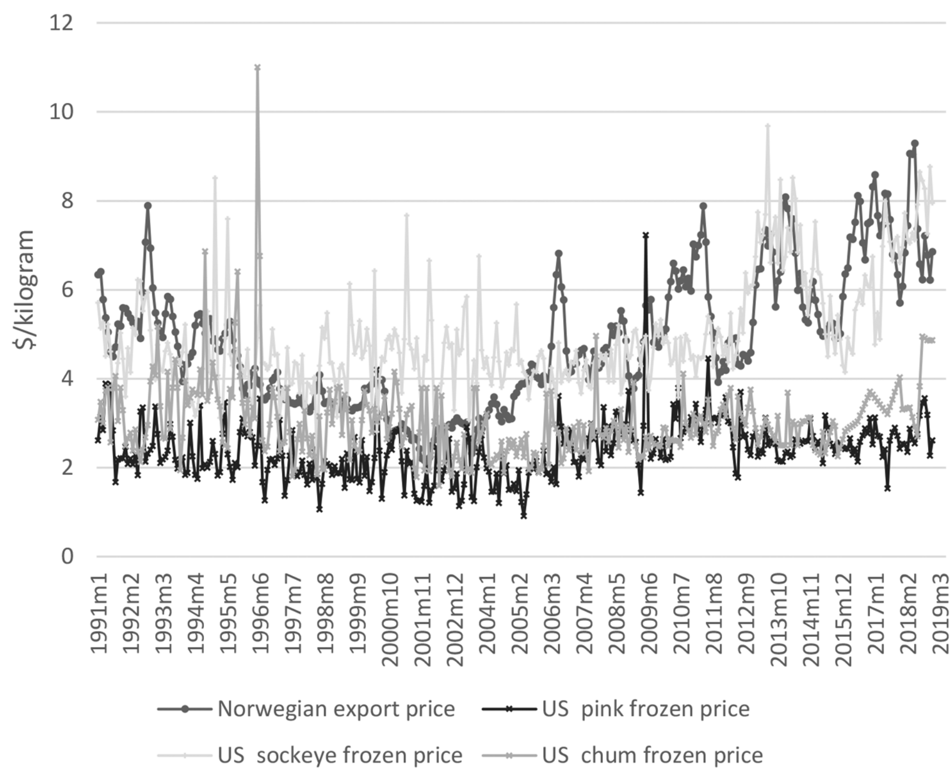

Figure 7. Development of Norwegian Real Export Price of Atlantic Salmon and US Real Export Price of Frozen Sockeye, Frozen Pink, and Frozen Chum

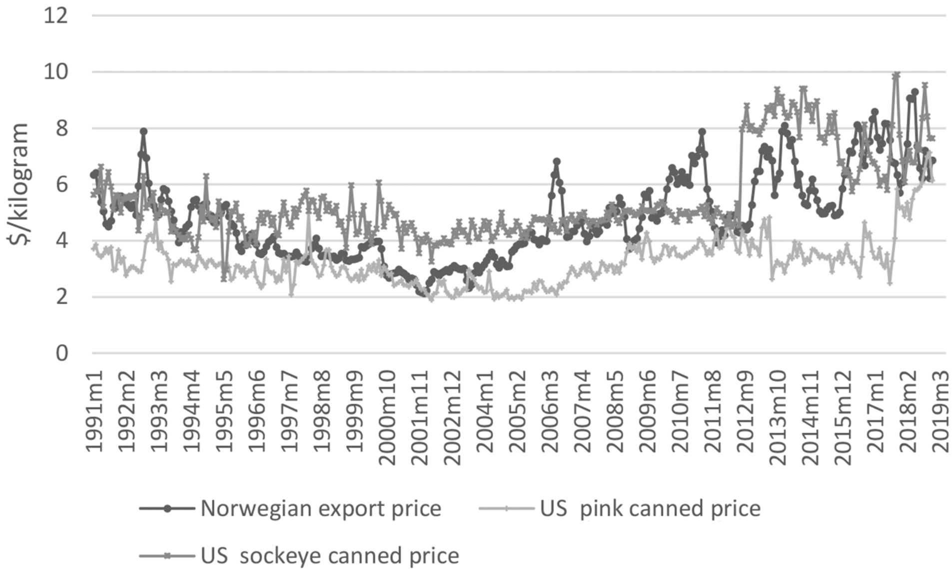

Figure 8. Development of Norwegian Real Export Price of Atlantic Salmon and US Real Export Price of Canned Sockeye and Canned Pink

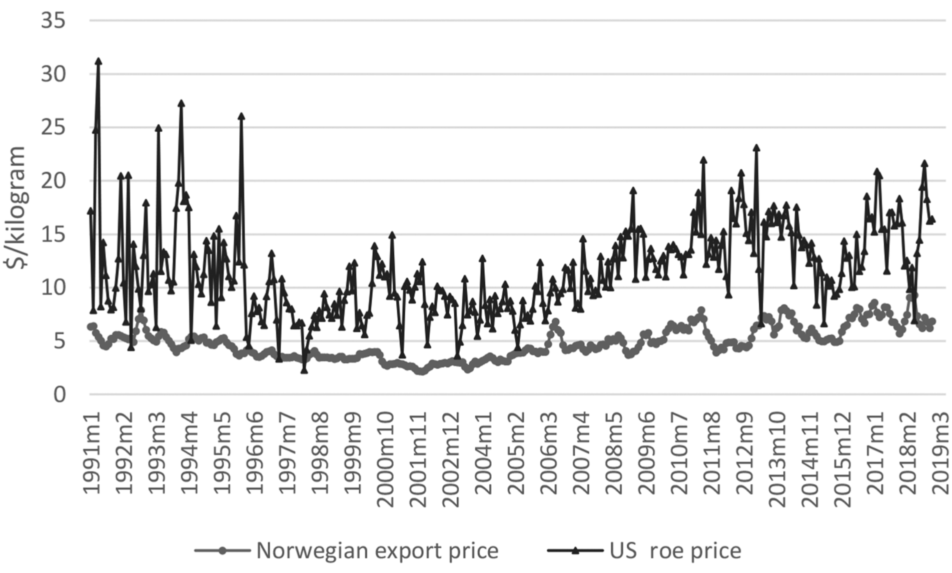

Figure 9. Development of Norwegian Real Export Price of Atlantic Salmon and US Real Export Price of Exported Salmon Roe

Figure 9 illustrates the price series of Norwegian salmon exports, together with export price of US salmon roe.[16] Roe is a valuable product and, with only a few exceptions, its price has been significantly higher than that of farmed salmon over our sample period. The variation in price is

16. The roe price is an index containing the export price of both frozen and cured roe.

also much larger for roe than for farmed salmon, particularly in the first part of the data series. The large yearly variation in prices mainly reflects year-to-year changes in Japanese domestic supply and import supply, as well as longer-term changes in demand for salmon roe products (Knapp, Roheim, and Anderson 2007). Since markets for salmon roe are driven by different factors than markets for farmed salmon, they are believed to be completely distinct from farmed salmon markets. It is also hard to spot a relationship between the two price series, but it seems that salmon roe has faced a downward price trend over the 1990s that has rebounded to an upward trend since the early 2000s. Summary statistics for all variables are reported in table 1.

EMPIRICAL RESULTS

Since the test for cointegration depends on the time series property of the data, we first conduct an augmented Dickey-Fuller (ADF) test for stationarity. Table 2 reports the result for the ADF test. Akaike's information criterion (AIC) is used to decide lag length and whether to include a constant term or a trend in the tests. For all price series, nonstationarity cannot be rejected at 5% in levels but is rejected for all prices in first difference.

Table 3 reports the bivariate cointegration results for the Norwegian export price of salmon and the US export price of salmon, for the aggregated market and for individual salmon products, and for the full sample period and the subperiods 1991–2002 and 2003–2018. We test for cointegration, using Johansen's trace test and maximum eigenvalue test (max test), testing the null hypotheses of at most *r* cointegration vectors. The models are specified with unrestricted constant and lag levels, to match the majority of the performed lag-order selection tests.

Both the trace and the max tests fail to reject the null of no cointegrating vectors at the 1% level for each of the bivariate time series tested, indicating that all price series are cointegrated. This is in line with what has been reported in other studies (Asche, Bremnes, and Wessels 1999; Asche 2001; Asche et al. 2005; Asche, Misund, and Oglend 2016; Asche, Cojocaru, and Sikveland 2018; Landazuri-Tveteraas et al. 2021; Salazar and Dresdner 2021). A concern is that, for all the frozen US prices and the price of roe, the null of only one cointegrating vector is rejected in favor of the alternative hypothesis of two cointegrating vectors at a 5% significance level. This implies that both data series are stationary. As this contradicts all the results of the ADF tests, we proceed, assuming that there is one cointegration vector.

Table 2. Augmented Dickey-Fuller (ADF) Test for Stationarity

	1991–2018		1991–2002		2003–2018	
	Level	First Difference	Level	First Difference	Level	First Difference
Norwegian	–3.305	–12.049**	–3.135	–8.157**	–2.811	–8.989**
US aggregate	–2.853	–13.120**	–2.716	–10.916**	–2.293	–10.773**
Sockeye frozen	–2.522	–15.206**	–2.192	–10.466**	–3.201	–15.216**
Pink frozen	–2.753	–13.194**	–2.813	–10.656**	–2.822	–10.558**
Chum frozen	–3.394	–13.847**	–2.198	–10.991**	–2.267	–10.265**
Sockeye canned	–2.801	–12.548**	–1.840	–10.481**	–2.495	–9.649**
Pink canned	–0.449	–12.761**	–2.629	–8.753**	–1.795	–9.312**
Salmon roe	–2.990	–12.120**	–2.799	–8.285**	–2.427	–12.079**

Note: ** Indicates significance at the 5% level.

Table 3. Bivariate Johansen Tests

				Time Period			Critical Value	
Price Series 1	Price Series 2		Rank = r	1991–2018	1991–2002	2003–2018	5%	1%
Norwegian	US aggregated	Trace test	$p=0$	68.5865	47.2484	36.9892	15.41	20.04
			$p\leq 1$	6.5808	5.5542	5.4615	3.76	6.65
		Max test	$p=0$	62.0057	41.6942	31.5277	14.07	18.63
			$p\leq 1$	6.5808	5.5542	5.4615	3.76	6.65
Norwegian	Sockeye frozen	Trace test	$p=0$	30.7112	56.7419	17.4274	15.41	20.04
			$p\leq 1$	3.5494	5.9258	3.7936	3.76	6.65
		Max test	$p=0$	27.1618	50.8161	13.6337	14.07	18.63
			$p\leq 1$	3.5494	5.9258	3.7936	3.76	6.65
Norwegian	Pink frozen	Trace test	$p=0$	58.2590	71.3691	30.7646	15.41	20.04
			$p\leq 1$	4.5800	5.4065	4.8681	3.76	6.65
		Max test	$p=0$	53.6790	65.9626	25.8965	14.07	18.63
			$p\leq 1$	4.5800	5.4065	4.8681	3.76	6.65
Norwegian	Chum frozen	Trace test	$p=0$	45.1081	47.0397	52.1799	15.41	20.04
			$p\leq 1$	4.4841	5.8467	6.6215	3.76	6.65
		Max test	$p=0$	40.6240	41.1930	44.8622	14.07	18.63
			$p\leq 1$	4.4841	5.8467	6.6215	3.76	6.65
Norwegian	Sockeye canned	Trace test	$p=0$	24.4929	25.1561	23.9355	15.41	20.04
			$p\leq 1$	1.4717	3.4147	2.7404	3.76	6.65
		Max test	$p=0$	23.0212	21.7414	21.1951	14.07	18.63
			$p\leq 1$	1.4717	3.4147	2.7404	3.76	6.65
Norwegian	Pink canned	Trace test	$p=0$	25.3705	24.2678	19.3328	15.41	20.04
			$p\leq 1$	1.6799	2.6221	2.8863	3.76	6.65
		Max test	$p=0$	23.6906	21.6457	16.4465	14.07	18.63
			$p\leq 1$	1.6799	2.6221	2.8863	3.76	6.65
Norwegian	Salmon roe	Trace test	$p=0$	82.4826	42.5135	41.0146	15.41	20.04
			$p\leq 1$	7.0578	5.7243	4.0101	3.76	6.65
		Max test	$p=0$	75.4248	36.7892	37.0045	14.07	18.63
			$p\leq 1$	7.0578	5.7243	4.0101	3.76	6.65

Having found a cointegration relation, we fit a VEC. Table 4 reports the cointegration vector and the test for LOP, for the full sample period and the subperiods 1991–2002 and 2003–2018.[17] The cointegration vector is normalized to 1 for the Norwegian salmon price. As shown in the table, the cointegration vector is in general closer to –1 for the latest period, indicating that the LOP is more likely to hold in this period. This is also confirmed by the log likelihood test statistics. Roe is the only product where LOP is found to hold in both subperiods. This is unexpected, as roe was predicted to be completely distinct from farmed salmon markets, since there is very little roe production from farmed salmon, and the roe market is presumably affected by factors other than those affecting the farmed salmon market. However, this suggest that there are sufficient strong relationships in the harvesting process to maintain a strong relationship. Estimates indicate that the LOP holds in both subperiods, but the log likelihood test statistic is stronger for the last subperiod (2003–18), indicating that the degree of market integration is getting stronger over time. This might be explained by the growing importance of roe from farmed trout.

17. To test for misspecification, we conducted the Lagrange multiplier (LM) test for autocorrelation in the residuals of the VEC models. At the 5% level, most tests (14/21) cannot reject the null hypothesis that there is no autocorrelation in the residuals, and, at the 1% level, all except one test (20/21) cannot reject the null hypothesis that there is no autocorrelation in the residuals. This indicates that the autocorrelation is less of a problem in our data.

Table 4. Cointegration Coefficient and LOP Test

Price Series 1	Price Series 2	1991–2018 Cointegr. Vector (β)	1991–2018 LOP $\beta = (1, -1)$	1991–2002 Cointegr. Vector (β)	1991–2002 LOP $\beta = (1, -1)$	2003–2018 Cointegr. Vector (β)	2003–2018 LOP $\beta = (1, -1)$
Norwegian	US aggregate	–2.3305	32.8290	–3.4007	27.6130	–1.8448	10.1430
			(0.0000)		(0.0000)		(0.0014)
Norwegian	Sockeye frozen	–1.8965	7.5039	–9.3830	31.1570	–1.1119	0.0015
			(0.0062)		(0.0000)		(0.9687)
Norwegian	Pink frozen	–2.0295	23.0040	–2.1671	25.5840	–1.9535	9.3056
			(0.0000)		(0.0000)		(0.0023)
Norwegian	Chum frozen	–4.8530	28.0080	–7.2531	29.7540	–6.7843	30.3850
			(0.0000)		(0.0000)		(0.0000)
Norwegian	Sockeye canned	–1.3440	1.7004	–3.5822	12.7670	–1.0391	0.0082
			(0.1922)		(0.0004)		(0.9280)
Norwegian	Pink canned	–1.2777	0.9637	–2.0295	10.6790	–0.9436	0.1624
			(0.3263)		(0.0011)		(0.6870)
Norwegian	Salmon roe	–1.3397	5.1335	–1.6562	3.1935	–1.1043	0.9105
			(0.0235)		(0.0739)		(0.3400)

Note: *P*-values are in parentheses.

Table 5. Weak Exogeneity

Price Series 1	Price Series 2	1991–2018	1991–2002	2003–2018
Norwegian	US aggregate	–0.04183	–0.01603	–0.07452
		(0.003)	(0.303)	(0.002)
US aggregate	Norwegian	0.14522	0.17145	0.13194
		(0.000)	(0.000)	(0.000)
Norwegian	Sockeye frozen	–0.01974	–0.00005	–0.05644
		(0.106)	(0.987)	(0.019)
Sockeye frozen	Norwegian	0.14510	0.08483	0.10350
		(0.000)	(0.000)	(0.009)
Norwegian	Pink frozen	–0.00600	–0.02394	–0.00538
		(0.631)	(0.033)	(0.765)
Pink frozen	Norwegian	0.28114	0.39228	0.23573
		(0.000)	(0.000)	(0.000)
Norwegian	Chum frozen	–0.00709	0.00082	0.00062
		(0.350)	(0.883)	(0.924)
Chum frozen	Norwegian	0.09863	0.09620	0.08059
		(0.000)	(0.000)	(0.000)
Norwegian	Sockeye canned	–0.04896	–0.00935	–0.08833
		(0.001)	(0.405)	(0.000)
Sockeye canned	Norwegian	0.07581	0.10611	0.06490
		(0.000)	(0.000)	(0.008)
Norwegian	Pink canned	–0.04260	–0.00603	–0.08067
		(0.009)	(0.802)	(0.002)
Pink canned	Norwegian	0.10441	0.22226	0.07740
		(0.000)	(0.000)	(0.029)
Norwegian	Salmon roe	–0.02520	–0.00564	–0.07860
		(0.015)	(0.532)	(0.001)
Salmon roe	Norwegian	0.38409	0.37570	0.33662
		(0.000)	(0.000)	(0.000)

Note: *P*-values are in parentheses.

While the LOP only holds for Norwegian salmon and roe in the first period, it additionally holds for frozen sockeye and both canned pink and sockeye in the second subperiod (2003–18), indicating that the market for these products became more integrated over time. This is as expected, as the world market is growing, and the logistics are becoming more efficient, making distances smaller and competition greater. Trade restrictions, on the other hand, could have opposite effects. For frozen pink and frozen chum, we do not find the LOP to hold in any period. Frozen pink and chum are lower-value species that were not exported in large quantities from the US until early 2000, when the landings and export of frozen sockeye decreased significantly.

The adjustment parameter is used to identify a price leader. As can be seen from table 5, the Norwegian export price is found to be weakly exogenous in relation to all US salmon price series for the 1991–2002 subperiod. The null hypothesis of endogeneity is rejected at the 5% or 1% level of significance for Norwegian farmed salmon in relation to all US price series. Our results are hence in accordance with other studies conducted for this period (Asche, Bremnes, and Wessells 1999) and illustrate the influence that the Norwegian salmon had on the price of other species throughout this time. Looking at the 2003–18 subsample, the picture changes. In this period, endogeneity cannot be rejected for Norwegian salmon in relation to the canned species or roe. These results can be interpreted to suggest that, as the market for these species and product forms is becoming tighter over time, Norwegian salmon has lost influence as the market leader. On the other hand, for the frozen species, Norwegian salmon is still found to be the price leader, while for sockeye the weak exogeneity of salmon is only significant at the 1% level. This is according to theory. Both frozen pink and chum belong to a smaller market than does wild sockeye, and it is therefore expected that, to a larger extent, they act as followers.

DISCUSSION AND CONCLUSION

In this paper we evaluate the degree of market integration between several product types of US wild salmon and Norwegian farmed salmon, the market leader. While several studies have investigated the link between farmed salmon and frozen wild and/or fresh wild salmon, to our knowledge, no study has yet included canned salmon and salmon roe in the analysis. Understanding how canned salmon and salmon roe are related to the rest of the salmon market is of particular importance to the US salmon market, since canned salmon and roe account for up to 38% and 27% of the US export value from salmon. For our analysis, we utilize a sample consisting of Norwegian export price of farmed salmon prices and US export price of wild-caught frozen and canned salmon and salmon roe, covering the period 1991–2018. Over this time, the US export market for salmon changed significantly, creating a need to provide an updated and expanded study reflecting current markets and market conditions, as well as documenting how the market has developed over time.

Further, our time series are characterized by periods of both increasing and decreasing prices. The first half of the study period is characterized by falling salmon prices, while the second half is characterized by increasing salmon prices. While most previous salmon market cointegration studies were conducted utilizing pre-2002 observations, our expanded time series enables us to investigate whether market prices of farmed Norwegian salmon and wild US salmon are cointegrated in periods of both decreasing and increasing prices. To investigate this, we utilize traditional Johansen market integration analysis and test whether the LOP and weak endogeneity hold in periods of both increasing and decreasing markets.

We find evidence of cointegration between the Norwegian farmed salmon market and the US frozen, canned, and roe market, in periods of both increasing and decreasing price trends. However, roe is the only product for which LOP holds in both subperiods: 1991–2002 and 2003–18. For the other product forms, the LOP appears to hold only in the 2003–18 subperiod for the major US salmon markets (frozen sockeye and canned sockeye and pink), indicating that these markets are becoming more integrated over time. For the smaller US salmon markets (frozen pink and chum), we do not find evidence of LOP. One explanation is that these products are considered lower quality than farmed Atlantic salmon or wild sockeye salmon. While Norwegian salmon was found to hold price leadership over all US species and product forms in the first subsample (1991–2002), price leadership seems to hold for frozen salmon only in the last subsample (2003–18).

A highly integrated market indicates that factors affecting the Norwegian salmon market will also affect the US wild salmon market. But what does it mean to American salmon fisheries that the price of their end product is closely related to and determined by the Norwegian Atlantic salmon price? Their sales price is likely to be affected by changes in price for Norwegian Atlantic salmon. Consequently, all factors determining the price for Norwegian Atlantic salmon may also have an indirect effect on the bottom line for US salmon fishery. The list of factors affecting the price of Norwegian Atlantic salmon is long. Besides demand and supply growth, which influence price directly, there are numerous environmental challenges (Liu, Lien, and Asche 2016), such as emissions, escapees, and disease (Fischer, Guttormsen, and Smith 2017; Abolofia, Asche, and Wilen 2017; Quezada and Dresdner 2017; Torrissen et al. 2013; Pincinato, Asche, and Roll 2021), that may affect prices indirectly, through halting production levels (Asche, Oglend, and Kleppe 2017), stricter regulations (Asche 2008; Osmundsen, Almklov, and Tveterås 2017; Hersoug, Mikkelsen, and Karlsen 2019),[18] and reduced growth in productivity (Asche, Roll, and Tveterås 2009; Asche and Roll 2013; Roll 2013; Rocha Aponte 2020). There has also been technological innovation at the farms (Torrissen et al. 2013) and within feeding (Asche and Bjørndal 2011), and nutritional developments, resulting in higher production levels at reduced costs, leading to reduced prices. Asche and Oglend (2016) show that there is a strong correlation between salmon prices and unit cost, and that the development of salmon price over recent decades has become more input price driven than productivity driven. Demand for Norwegian Atlantic salmon is also sensitive to environmental challenges and food safety (Sha et al. 2015). In addition, demand has been subject to political risks, such as the Russian ban of European food imports (Braw 2015), resulting in a short-term drop in demand. A doubling in volatility over the last 10 years is an indicator of the complexity of factors, both supply and demand, affecting salmon prices (Asche, Misund, and Oglend 2019).

While our results have shown that wild US salmon and farmed Norwegian salmon are cointegrated, the substitution is not perfect in all markets. Other factors, such as environmental and ocean conditions that impact the volume of annual US wild salmon returns, may hence create a natural supply response on US salmon price. Changes in consumer preferences for shelf-stable products relative to fresh or frozen products (for example, the high demand for storable food during the breakout of COVID-19) can influence relative prices among products within a given species. Marketing strategies that lie at the cross section between environmentally friendly

18. In a recent paper, Oglend and Soini (2020) found that the current regulatory regime may exacerbate the environmental impact.

harvesting and consumption of wild seafood can affect long-term trends in wild US salmon demand.[19] Especially within small niche markets, we expect the price of US wild salmon to be independent of the large world market. While farmed salmon is the most direct substitute for wild salmon, cod and other moderately priced seafood commodities can be imperfect substitutes to varying degrees. Investigating the degree to which the salmon market is integrated into these markets, we leave to future research.

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