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¿Qué podemos aprender de una crisis sanitaria? El virus ISA y los precios de mercado

What can we learn from a sanitary crisis? The ISA virus and market prices

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Abstract

To analyze the functioning of the Atlantic salmon market in the US, a Steen and Salvanes (1999) extension of the Bresnahan-Lau model was successfully estimated for the Chilean industry. We considered the period when Chilean producers were affected by the ISA virus. We found that in a disequilibrium scenario, the market remains competitive. Nevertheless, due that in the short-run there is some evidence of market power, it appears that during the recovery period the great offer of Atlantic salmon could have had an effect on price through the accumulated exercise of market power in the short-run. At the end, our results show that in the long-run the import price of Chilean Atlantic salmon is led by the fishmeal price, and this does not change significantly during the crisis.

Resumen

Para analizar el funcionamiento del mercado estadounidense del salmón Atlántico, se estimó con éxito la extensión del modelo Bresnahan-Lau desarrollada por Steen y Salvanes (1999) para la industria chilena del salmón. Hemos considerado el periodo donde los productores chilenos fueron afectados por el virus ISA. Nuestros resultados sugieren que en un escenario de desequilibrio, el mercado sigue siendo competitivo. Sin embargo, debido a que existe evidencia de poder de mercado en el corto plazo, al parecer la mayor oferta de salmón Atlántico durante el periodo de recuperación pudo haber tenido efecto sobre el precio de mercado a través de un ejercicio acumulado de poder de mercado en el corto plazo. Al final, nuestros resultados indican que en el largo plazo los precios de importación de salmón Atlántico chileno son liderados por el precio de la harina de pescado, y esto no cambia significativamente durante el periodo de crisis.

1. Introduction

Sometimes, when we study a market, this remains stable. This means that deviations from the equilibrium are small and the adjustment to the long-run trajectory can be achieved quickly. As a consequence, demand and production show smooth variations throughout the years and interesting information about how the market works is difficult to obtain. However, even though a market could be considered stable, it is not protected from exogenous shocks. Depending on the shock magnitude, different market issues can be possible to study. As an example, a supply shock allows us to study how the main consumers and competitors react. Maybe we also wonder if in this process some effect on margins perceived by producers could exist, or whether a crisis implies a higher unitary cost for firms.

In this study we analyze the functioning of the Atlantic salmon market and its price determination process for the Chilean salmon industry. We will focus on the United States (US) market for salmon because is the most important for Chilean farmers. Moreover, we have considered in our estimation sample the period when Chilean salmon producers were affected by an ISA (Infectious Salmon Anemia) virus pandemic, which would allow us to obtain additional information and better understanding about how the market works and how prices are determined.

In general, the global aquaculture production can be controlled by producers, hence, we most often assume that the salmon market is stable. However, between 2008 and 2010 the ISA virus crisis had a significant effect on Chilean production of Atlantic salmon, diverting the market from its long-run equilibrium. Besides the negative effect on production, this crisis had also a significant effect on employment. Between June 2007 and June 2009, the number of workers decreases in a 40% approximately (Subsecretaria de Pesca, 2013). Furthermore, during the ISA virus period, farmers were forced to temporarily close salmon farms, harvest early, and adopt control and preventive measures to confront the disease. Moreover, since April 2010, new regulations were issued to prevent future crises (Subsecretaria de Pesca, 2013). This may implies greatest cost for the industry due to, as an example, greater investments in salmon farms to improve sanitary conditions. However, the ISA virus pandemic provides an unique opportunity to study the market because the magnitude of this shock was unusual.

Analyze the functioning of the Atlantic salmon market for Chilean producers implies identifying if some effect on the margins ($MC > P$; where MC is the marginal cost of production and P is the market price) perceived by Chilean farmers could exist during the ISA virus crisis; the market stability during and after the sanitary crisis (whether it is possible to identify structural breaks in market parameters due to, for example, higher costs or changes in willingness to pay by consumers); how relevant the exogenous variables are in price determination (such as feeding cost or income); and how long does it takes the market to return to the long-run equilibrium.

Our attempt to understand the market reaction during the ISA virus crisis could be useful for improving the policy design to confront future supply shocks in the industry. For example, knowledge about how prices react when a crisis affect the industry allows to have an idea about what happens with benefits. Hence, preventive and employability measures could be designed. Moreover, understanding price determination is always useful for the design of management policies that consider the market price behavior as a relevant variable.

Furthermore, information obtained from this study could also be important for competition policy. Even though the ISA virus crisis was an exogenous event, in principle we could think that the same result in supply obtained due this pandemic could be possible to achieve by a hypothetical scenario where Chilean salmon producers collude. In other words, we are saying the same supply result produced uncoordinated by the virus crisis could, in principle, be obtained if Chilean producers gather together to restrict supply.

There is not a strategic behavior during the ISA virus crisis. Each farmer produces competitively, as a price-takers, and this behavior is reflected at the industry level. However, during the pandemic producers were forced to reduce their production and, in the aggregate, Chilean farmers produced a non-competitive level of salmon. This could have implied that the market price perceived by Chilean farmers would be greater than the price that they would have obtained if they had produced the competitive level as a group. Nevertheless, increasing marginal cost could also explain the higher price level observed in that period.

If this study indicates that the margins obtained by Chilean producers stayed stable before and during the ISA virus crisis, this means that the regulatory authority does not need to worry about a possible collusive behavior in the future. In this case, there is no room to exert market power in this market, at least while market structure remains steady over time.

The study of the functioning of the salmon market is a recurring topic in the empirical literature. In general, this literature has primarily focused on the study of market integration, price transmission and elasticities (*e.g.* Asche *et al.*, 2005; Asche *et al.*, 2007; Tveteras & Asche, 2008; Xie *et al.*, 2009). Other articles have focused on the market power issue (*e.g.* DeVoretz & Salvanes, 1993; Steen & Salvanes, 1999; Jaffry *et al.*, 2003; Asche & Steen, 2006; Fofana & Jaffry, 2008). Nevertheless, the latter studies were conducted on an equilibrium context. Now we have the opportunity to study the salmon market in a disequilibrium environment, which is the main contribution of this research.

2. Market description

The Chilean salmon industry is concentrated in the southern part of the country, mainly in the Los Lagos and Aysén regions. The reason for this concentration is that, in the coastal zones of these regions the climatic conditions are very similar to the prevailing ones in salmon's natural environment (Asche & Bjørndal, 2011). This competitive advantage could be the reason why since the mid-1980s the Chilean salmon industry has grown very quickly.

For Chilean producers, the Atlantic salmon (*Salmo salar*) is the most significant species. During the period 2007 - 2012, the period after and before the ISA virus crisis, the production of Atlantic salmon represented approximately 50% of Chilean total salmon production, while Coho salmon and Rainbow trout jointly responded for the other 50% (FAO, n.d.). Cultivated Atlantic salmon can be considered to be homogeneously produced by the Chilean producers, in terms of quality and processing form.

Atlantic salmon produced in Chile is principally exported. In the last years, approximately 90% of all exported fresh Atlantic salmon goes to the US (Servicio Nacional de Aduanas, 2014). In the case of frozen Atlantic salmon, Chilean exports are mainly distributed between the US and European Union (EU) with 24% and 38%, respectively, of the deliveries in 2008 (Asche & Bjørndal, 2011). The Japanese market is also important for Chilean farmers. Nevertheless, Japan is the main market for Coho and Rainbow trout, but not for Atlantic salmon.

The US is one of the largest salmon markets and is primarily dominated by imported salmon. Approximately 70% of the total salmon consumed in the US was imported in recent years. Furthermore, if we focus on Atlantic salmon, approximately 95% of the total consumption of this species in the US was imported (Fisheries Statistics and Economics Division, 2014; FAO, n.a.). This has not always been the case in the past. At the beginning of the 1990s, the total imports of all species of salmon represented about 40% of US market consumption (Clayton & Gordon, 1999). Between frozen and fresh salmon, the latter is the most important. In 2013, 81% of total salmon imports was fresh salmon (Fisheries Statistics and Economics Division, 2014). Nevertheless, in the last few years the imports of frozen salmon have gained ground gradually. The US imports of fresh and frozen salmon consists mainly of Atlantic salmon (Asche & Bjørndal, 2011), where Chile and Canada are the main suppliers. In 2013, approximately 46% of the US imports of Atlantic salmon came from Chile, principally as fillet salmon, and 29% came from Canada, principally as round salmon (Fisheries Statistics and Economics Division, 2014).

However, Chile and Canada have not always been the dominant countries. Before 1990, Norway was the dominant supplier of farmed Atlantic salmon in the US, where more than 50% of the total imports of this species came from that country (Clayton & Gordon, 1999). Nevertheless, in 1991, after several conflicts with Norwegian salmon exporters, the US authorities imposed an anti-dumping duty on Norwegian exports of fresh round salmon (which in January 2012 was repealed by the US International Trade Commission). This had the effect of driving out Norwegian producers from the US market. Then, Chilean and Canadian producers had the opportunity to increase their share of this market. Nevertheless, since 1999 there has been an attempt from Norwegian producers to recover the market through the export of fresh and frozen fillets, as well as frozen round Atlantic salmon, considering that those product forms were not affected by the anti-dumping policy (Asche & Bjørndal, 2011).

Between 2009 and 2010, the amount of imported Norwegian Atlantic salmon in the US market surpassed the Chilean one (Fisheries Statistics and Economics Division, 2014). However, this was due to the significant effect that the ISA virus pandemic had on Atlantic salmon production and exports in Chile. The critical period was from June 2008 to May 2009, where the greatest number of outbreaks was registered (Servicio Nacional de Pesca, 2012). The impact of the sanitary crisis on production was reflected since early 2009 until mid-2010. The production of Atlantic salmon in Chile was approximately 390,000 tons in 2008, while in 2010 this production decreased to 120,000 tons (FAO, n.d.). At the end of 2010, the Chilean production started to recover and by 2012 the production level was similar to the obtained in 2008.

a. Price development in the US market

Figure 1 shows the moving averages of the import price and imported quantity of Chilean Atlantic salmon in the US market. At first sight, we can observe that there is a negative correlation between price and quantity in the shaded area (the period between February 2009, when the ISA virus started to affect salmon production in Chile, and December 2012, when Chilean farmers had recovered from the crisis). However, this correlation is not evident along the rest of the sample period. For example, we can observe that from 2002 to 2004 the quantity exported continuously grows, but that the price level remained stable without trend between mid-2002 and mid-2005. Moreover, between mid-2005 and mid-2006 a rapid increase of price ocurred while the quantity fell slowly.

One hypothesis for the strong correlation observed during the ISA virus period is that the Chilean industry of Atlantic salmon was capable to affect the market price. Hence, when production falls significantly, the price increases, and later when production recovers, the price falls back.[1] However, there might be other reasons that could explain, at least partially, the observed changes in the price during this period. Some reasons could be: higher production costs on the supply side driven by the general food price trends, could imply a cost push increase in prices; the potential negative impact that the ISA crisis had on the image of the Chilean salmon industry; the financial crisis that affected the main consumer countries of salmon that could also involve a demand contraction. So, the potential explanations are several and need to be tested before we can be sure of the forces that drive prices.

Since the literature indicates that there are no separated markets for fresh salmon globally (see *e.g.* Asche *et al.*, 1999; Asche, 2001), we also need to incorporate in the analysis the production of other salmon-producing countries to understand price variation. Considering the US market, Atlantic salmon from Canada and Norway could be regarded as product substitutes for Chilean Atlantic salmon. Nonetheless, other salmon-producing countries (mainly producers of Atlantic salmon) could also be considered as potential entrants. For example, the United Kingdom (UK) and the Faroe Island.

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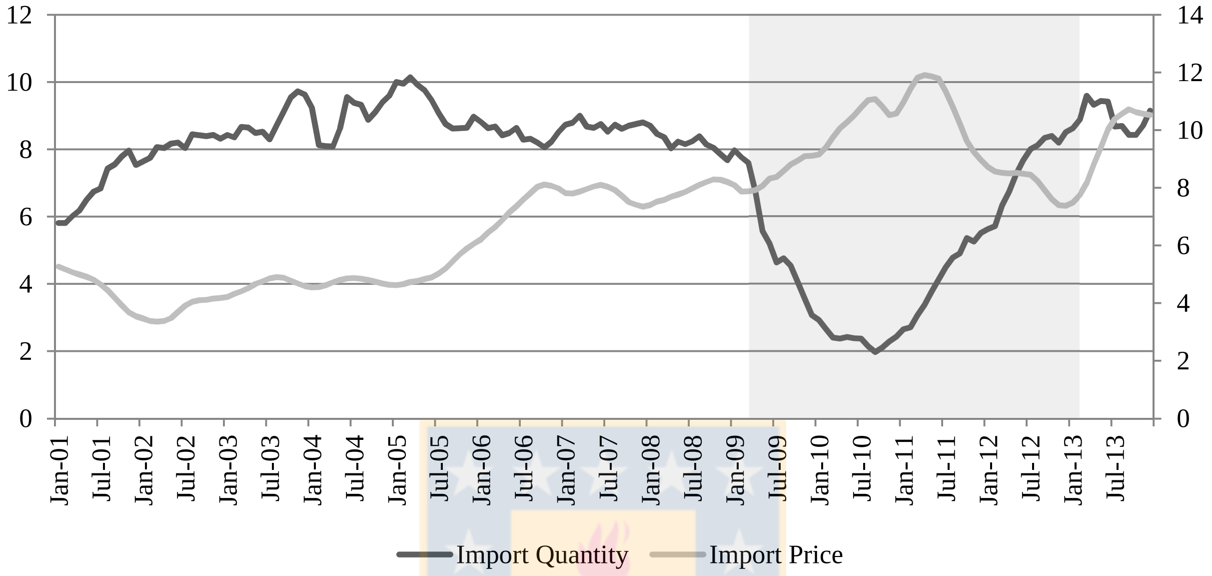
[1] This view is widely held among Chilean salmon producers, as it has been posible to know by personal communications.

FIGURE 1. Moving averages of the import price and imported quantity of Chilean Atlantic salmon in the US market between January 2001 and December 2013. The right hand axis shows import prices per kilogram (US$/kg) and the left hand axis shows the quantity imported measured in thousands of tons. *Source*: NMFS.



The US market for salmon is interconnected with other major market such as the EU market or the Japanese market (see *e.g.* Asche, 2001). Therefore, even though Chilean producers supply a large part of Atlantic salmon consumed in the US market, while Norwegian and Canadian farmers offer a smaller amount, this does not ensure that the Chilean salmon industry has the capability to affect the price. The reason is simple: if the EU salmon price is lower than in the US, this should induce a shift in the supply of salmon offered from the EU to the US market. Price arbitrage is at work between the US and other salmon markets.

Therefore, any action taken by Chilean producers, which in the aggregate could affect the price positively implies that potential entrants (salmon-producing or potentially salmon-producing countries) will have higher incentives to compete in this market and threat Chilean producers' market share. One possible reason why potential entrants do not participate in this market is that the market price is not high enough to cover their marginal costs. However, if the price increases, it will probably do. Maybe the reason why Chilean farmers behave as price-takers is due to this contestability.

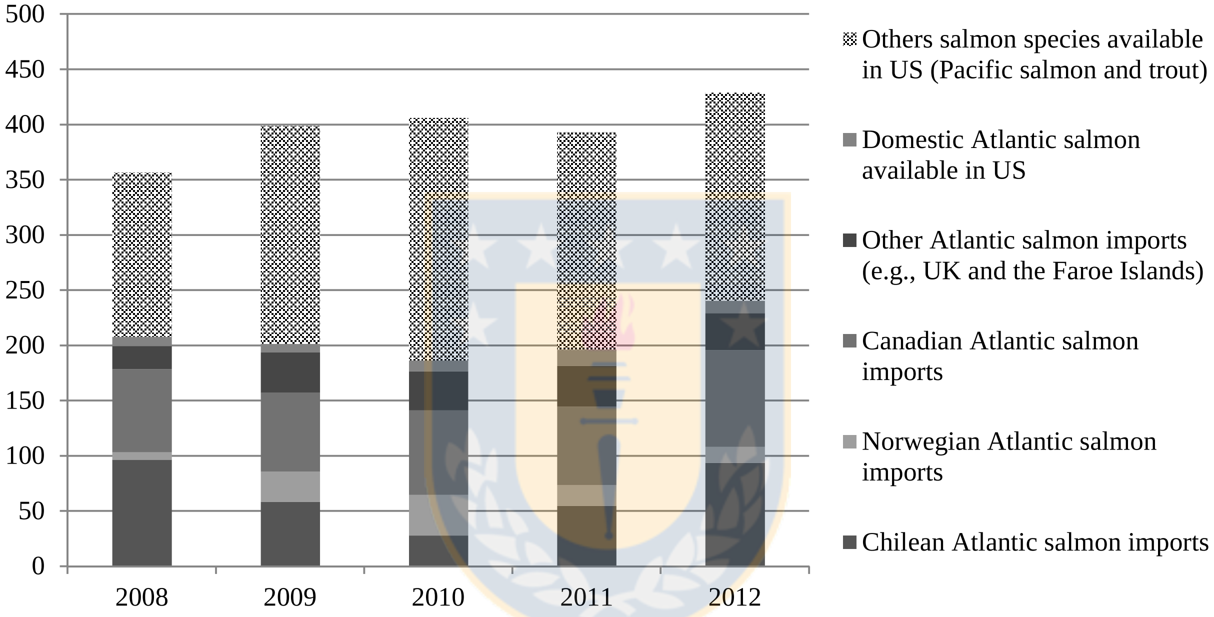
However, although large salmon producers, such as Norway, keep track on price developments in global markets, they cannot react instantaneously to large changes, even though they have idle capacity (see Andersen *et al.*, 2008; Asheim *et al.*, 2011). This is due to both logistics (such as transport or processing) and biological issues. They have adjustment costs to consider when they decide to change the production level. Hence, it seems reasonable to assume that the Chilean industry has the capability to affect the price in the short-run. This is a result obtained by Steen and Salvanes (1999) for Norwegian industry at the French salmon market. They found that Norwegian producers exercise market power in the short run, probably due to the seasonal structure of the Pacific salmon industry.

The previous discussion assumes that, in the long-run, competitor countries can substitute completely the Atlantic salmon imports from Chile in the US market and, hence, that price will not change. Only a market share reallocation will exist and no effect on market price would be possible. Nevertheless, due to the large effect on production caused by the ISA virus, probably the effort required to substitute the lower production of Chile in that period was too high, therefore, global producers could only partially substitute Chilean production. This will depend on rigidities in supply, such as infrastructure and environmental constraints, exist. In this case, the capability to affect the price in the short-run might have been maintained during the time that the sanitary crisis took place. Moreover, if this partial substitution ocurred on a global scale, the lower production of salmon in the world should have created a global pressure on the salmon price and, therefore, we can talk, to some extent, about the capability of Chilean producers to affect the market price. The duration of this “over normal” price will depend on the capability of global producers to overcome these rigidities.

Figure 2 shows the estimated salmon supply in the US market during the ISA virus crisis. It is apparent from this chart that a substitution between Chilean and Norwegian production ocurred. In the meanwhile, Canadian farmers maintained constant their export share in the US market, probably because they had limitations to increase production (Asche & Bjørndal, 2011). Other salmon-producing countries, such as the UK and the Faroe Islands, also increased their export to the US market in this period. Nevertheless, if we consider the total estimated supply of Atlantic salmon in the

US, the level reached in 2010 was lower than in 2008. Apparently, the Chilean production was not fully substituted by other Atlantic salmon producers. Accordingly, we should expect a positive effect on the price as a consequence of this supply reduction.

FIGURE 2. Estimated salmon supply in the US market during the ISA virus crisis 2008 – 2012 in thousands of tons. Domestic production available in US was estimated using export and production statistics. *Source*: FAO and NMFS.



However, the salmon market limits are diffuse. If we consider that the US Pacific salmon could be a substitute for Atlantic salmon and, moreover, that the US is one of the principal suppliers of wild Pacific salmon in the world, then the total available supply of salmon is enlarged. Some studies indicate that, although Atlantic salmon is principally farmed and Pacific salmon is mainly wild-caught, these two species compete in the same market (e.g. Asche *et al.*, 1999; Clayton & Gordon, 1999). If we consider the supply of Pacific salmon as part of the market supply, then the total supply of salmon during the ISA virus crisis was higher than in 2008 (see Figure 2). If this was the case, the observed increase in prices could not be explained by insufficient supply.

Alternatively, the accelerated recovery of Chilean production started in August 2010, maybe encouraged by the high market prices observed in the previous periods, together with the higher supply of Pacific and Norwegian Atlantic salmon compared to 2008, caused that the Atlantic salmon supplies, as well as the total salmon supplies, increased considerably in 2012. Maybe this could be the reason why in 2012 the price was lower than in previous years.

To some extent, Rainbow trout could also be considered a substitute of Atlantic salmon. However, in the US market this species is not consumed in a considerable amount. Also one might think that others fish species highly marketed in the US could also be considered a substitute of salmon, but some studies indicate that there is little or no substitution in this case (e.g. Jaffry *et al*., 2000; Asche *et al*., 2002).

The latter discussion is related to the demand price elasticity. In the case that there are few substitutes for Atlantic salmon, the elasticity of demands become less price elastic to the point that it can be considered inelastic, and the Chilean Atlantic salmon producers can be in position to affect prices by small reductions in the quantity exported. In the case that demand is price elastic, a reduction of the quantity exported might not have a significant effect on the price. Recent research finds that the demand for fresh farmed salmon in world markets is becoming less price elastic (*e.g.* Xie *et al*., 2009).

Lets focus on Atlantic salmon. One question that arises is why Norwegian farmers, which are the largest producers of Atlantic salmon globally, did not cover completely the production fall of Chilean salmon during the crisis. When we see global statistics, we can observe that Norwegian production maintained its trend during this time (FAO, n.d.). It is likely that the incomplete substitution is due to entry barriers that Norwegian producers faced. According to Asche and Bjørndal (2011), trade tensions seem to be a constant barrier for Norwegian producers that limit production growth, as for example the anti-dumping duty imposed by the US.

Nevertheless, domestic Norwegian regulations, such as the feed quotas in the past or the licenses regime, could also be considered a limiting factor for production growth. As in the other salmon producing regions, a licensing regime is in place (farm permits). This regime constrains the maximum production for each company in order to regulate the competition and guarantee a sustainable industry. However, the Maximum Allowed Biomass (MAB) assigned by licenses seems not to have been a problem during the ISA virus period, since the total biomass obtained each year during this period was far from the maximum allowed biomass (see Marine Harvest, 2014).

Other general facts could also be useful to explain the incomplete substitution. First, the growing of Atlantic salmon takes approximately two years, so an adjustment to changing market conditions will always be slow. On the other hand, uncertainty about the real effect of the ISA virus on Chilean supply and on demand development might have made very difficult for salmon producers to react in a appropriated way to the case. Norwegian producers had to decide in 2008 the production level of supply in 2010. Hence, there was a risk of overshooting production associated to this decision (Andersen *et al.*, 2008). Lastly, maybe the demand of Atlantic salmon in the US was contracted due to the subprime crisis and the magnitude of the expected demand was unknown. Hence, an incomplete substitution could be a natural reaction of Norwegian producers to the prevailing economic context at that time.

In summary, we have different possible hypotheses about what were the forces acting behind the price development of Chilean Atlantic salmon in the US market during the ISA virus period. The main ones are: the Chilean industry’s capability to affect the price in the short run, the US demand contraction that partially corresponded in time to the sanitary crisis period, an increasing trend in production costs, or a combination of these. An accurate explanation, that can discern between alternative explanations, is not possible unless a more sophisticated methodology is used.

3. Materials and Methods

A suitable approach to study the functioning of a market over time is the Error Correction Model (ECM). This approach uses a cointegration analysis, which allows us to deal with the inherent non-stationary nature of the variables that we consider in this research. Moreover, this model allows for the inclusion of lags in the system equations. Hence, we could analyze the short and long run behavior of the market and determine how much time does the market require to return to its stationary equilibrium.

However, consider the possible effect on price in the short-run and during the ISA virus period. If we uncorrectly assumed that the Chilean salmon farmers did not have the capability to affect the price or to exercise market power, our estimates of the market parameters would be biased (Perloff *et al.*, 2007). The effect of the supplied quantity on prices is another variable to be estimated. Its exclusion could imply an omitted variable bias problem.

To tackle this issue, we decided to use a simple structural approach based on static games: the Steen and Salvanes (1999) extension of Bresnahan-Lau (BL) static model for homogeneous goods (Bresnahan, 1982; Lau, 1982). Most often, the BL model is used to estimate market power at the industry level. The model can be used to capture a possible effect on price by an industry that behaves as price-taker. It only requires some reinterpretation of its theoretical basis and results.

Steen and Salvanes (1999) extension estimated an ECM including a parameter that captures different market structures. Moreover, both demand and supply functions were estimated in their structural form, so that elasticities can be analysed and includes different explanatory variables that affect supply and demand separately. In summary, the Steen and Salvanes (1999) extension allows us to study how the market works in the long-run as well as in the short-run, what their market parameters are, and take into account the potential capability to affect the price by the industry in a given period as well as in the short-run.

a. Theoretical model

If we have explicit information about marginal costs, determining whether an industry exercises market power or has the capacity to affect the market price is easy. We just need to compare price with marginal cost. However, usually we only observe the price and related costs and demand variables (Perloff *et al.*, 2007). The BL model allows us to ignore that problem by estimating if an industry is faced with prices above marginal cost and the marginal cost simultaneously (Perloff *et al*., 2007).

When we use industry level data, we need to assume that firms' products are homogeneous. In our empirical case, this means that all Chilean farmers of Atlantic salmon produce an homogeneous product, which in general terms does not seems to differ from actual conditions. This enables us to use average market price and total output. Moreover, this model assumes that all firms are identical, so they behave in the same manner and their marginal costs are the same (Perloff *et al.*, 2007).

Hence, let us assume that product is homogeneous among firms. Moreover, assume that Chilean firms are identical. The demand function (*D*) that the industry faces is:

$$Q = D\left(P, Z; \delta\right) + \varepsilon \tag{1}$$

where P is the price of output, Q is the quantity of output, Z is a vector of exogenous variables that affect the demand function, δ are the unknown parameters of the demand function to be estimated and ε is a disturbance term that shifts the demand function. Most often income and price of substitutes are used as exogenous variables. On the other hand, the marginal cost (*MC*) is:

$$MC = g(Q, W; \varphi) + \mu \tag{2}$$

where $g(\cdot)$ is the marginal cost function, W is a vector of exogenous variables that affect the marginal cost, for example the price of inputs, φ are the unknown parameters of the marginal cost function to be estimated and μ is a disturbance term that shifts the marginal cost function. The marginal revenue (*MR*) is

$$MR = P + \frac{\partial D^{-1}(Q, Z; \delta)}{\partial Q} Q = P\left(1 + \frac{1}{\eta}\right) \tag{3}$$

where $D^{-1}(\cdot)$ is the inverse demand function and η is the elasticity of demand. To incorporate various potential market structures, the parameter λ could be included in the marginal revenue function. The marginal revenue can be rewritten as the perceived marginal revenue (*PMR*):

$$PMR(\lambda) = P + \lambda \frac{\partial D^{-1}(Q, Z; \delta)}{\partial Q} Q = P\left(1 + \frac{\lambda}{\eta}\right) \tag{4}$$

The optimal condition, or the supply function for the industry, is when perceived marginal revenue equals marginal cost:

$$PMR = P + \frac{\lambda P}{\eta} = g(Q, W; \varphi) = MC \tag{5}$$

If $\lambda = 0$, then equation (5) is transformed to a marginal cost pricing formula. Hence, the industry cannot affect the price. If $\lambda = 1$, the result is similar to that obtained in monopoly or perfect collusion scheme. The industry affects the price to the point that they perceived a monopoly marginal revenue. An intermediate result, $0 < \lambda < 1$, indicates the degree in which the industry can affect the price. Hence, λ is the percentage of monopoly marginal revenue perceived (Steen & Salvanes, 1999). The basic static model consists in a system formed by the demand equation (1) and the supply equation (5).

Some literature interprets λ as an aggregate conjectural variation. The conjecture of a firm is its belief or expectation of how its rivals will react to changes in its output (Church & Ware, 2000). Nevertheless, we consider in this work that salmon producers behave as price-takers individually and thus this behavior is reflected at the industry level. Hence, a strategic interpretation of λ is not appropriated. Therefore, we used another interpretation based on the Lerner index, which measures the percentage markup of price over marginal cost. We can rewrite equation (5) as $P - MC = -\lambda P / \eta$. The Lerner index is defined by $L = \frac{P-MC}{P}$, hence, dividing $P - MC$ by P we obtain $L = -\lambda / \eta$.

In this context, some econometricians argue that λ can be interpreted as an index of market power, due that λ takes the role of the HHI index on the Lerner index obtained when we study the average price-cost margin for the industry (Perloff *et al.*, 2007). Nevertheless, according to our case, we interpreted λ as an index of the degree in which the industry affects the price exogenously. $L = -\lambda / \eta$ also indicates that the percentage markup of price over marginal cost depend on the elasticity of demand. This means that, independently of the value that λ takes, if the elasticity is high then the Lerner index will be low.

b. Empirical model

To apply the model reviewed to the US Atlantic salmon market, we assume that Chilean salmon producers face a log-linear ordinary demand:

$$\ln Q_t = \delta_0 + \delta_1 P_t + \delta_2 Z1_t + \delta_3 Z2_t + \delta_4 Y_t + \delta_5 PZ2_t + \delta_{Image} D_I Y_t + \varepsilon_t \tag{6}$$

where ln*Q* is the logarithm of the imported quantity of Chilean Atlantic salmon in the US market, *P* is the import price of Chilean Atlantic salmon in levels, *Y* is a proxy variable that represents the US market income and *t* is the subscript that denotes the time period. The Personal Consumption Expenditures (PCE) of the US in levels is used as this proxy variable. *Z1* and *Z2* are the price of the Canadian Atlantic salmon and the price of the US Pacific salmon (both in levels), respectively. D_I is a dummy variable that adopts the value of one between March 2008 and December 2011. $D_I Y$ is an interactive variable included to identify structural breaks on the willingness to pay for Chilean salmon during the ISA virus period. We want to test the hypothesis that the image of the Chilean salmon among consumers, was negatively affected by the sanitary crisis, principally between March 2008, when the main newspapers of the US informed about this new virus which affected the Chilean salmon industry due to a lack of sanitary conditions (see *e.g.* Barrionuevo, 2008), and December 2011, one year after the last ISA virus outbreak was registered (Servicio Nacional de Pesca, 2012). Therefore, we expected δ_{Image} to be negative. Finally, *PZ2* is an interactive variable that is included in the model because it is capable of rotating the demand curve and, therefore, allowing us to solve the identification problem of λ (see *e.g.* Church & Ware, 2000). Under perfect competition, the demand curve rotates around the market equilibrium, so there is no effect. However, if there is some degree of market power, equilibrium price and quantity will respond to a rotation in demand. The demand curve rotation shifts the perceived marginal revenue of the industry, and then it is possible to observe an effect on market equilibrium (see *e.g.* Church & Ware, 2000)[2].

In the US market, the price of the Norwegian Atlantic salmon moves very similar to the price of the Chilean Atlantic salmon. As we mentioned above, the salmon markets are highly integrated. There is no separate market for fresh salmon. Moreover, according to Asche and Bjørndal (2011), there is a close relationship between fresh and frozen. Since Norway and Chile export principally fillets to the US, it is not surprising, therefore, that these prices are highly correlated. To avoid multicollinearity, we decided to exclude the price of the Norwegian Atlantic salmon from the demand equation.

The price of the Canadian Atlantic salmon is a different case. Canada exports principally round salmon. As it was mentioned in Asche and Bjørndal (2011), to some extent this means that the production of Canadian farmers is targeted to a different market segment. In other words, the Canadian Atlantic salmon is an imperfect substitute of the Chilean Atlantic salmon.

The demand functional form chosen differs from Steen and Salvanes (1999). They used a linear specification for both the demand and supply relations. However, Perloff and Shen (2012) demonstrated that if both equations are linear, estimates in the BL model inherently suffer from a severe multicollinearity problem. To avoid this, they recommended to specify at least one of the equations as log-linear or as other functional form. We decided to use a log-linear specification for demand instead of another functional form because it is easier to derive the dynamic model from the stationary one in this case. For instance, the log-log functional form for demand gives a non-linear

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[2] An additional deterministic variable was included in preliminary estimation to control for the anti-dumping duty imposed to Chile by the US International Trade Commission in 1998. This dummy was activated at the beginning of the data sample until June 2003, when the anti-dumping duty was repealed. However, independent as how we specified the variable (as structural break or as an interactive variable with price), the estimated coefficient was always not significant. Hence, we decide for not to include in our final model.

static model. This nonlinearity makes it difficult to derive a dynamic model based on the structural specification of the stationary equation.

Considering the equation (6), the perceived marginal revenue is:

$$PMR_t = P_t + (\lambda + \lambda_{ISAv1} D_{ISAv1} + \lambda_{ISAv2} D_{ISAv2}) Q^*_t \tag{7}$$

where $Q^* = (\partial D^{-1}/\partial Q)\ Q = 1 / (\delta_1 + \delta_5 Z2)$ and λ, λ_{ISAv1}, λ_{ISAv2} are parameters to be estimated, which are discussed below (see Appendix A for the derivation of Q^*). The two interactive variables, $D_{ISAv1}Q^*$ and $D_{ISAv2}Q^*$, are included to capture potential effects on perceived revenue due to the large variations of Chilean production during the sanitary crisis. As discussed before, there is a chance that the complete substitution of Chilean production was not possible. In this case, the Chilean production shortfall might have affected the price over that period. $D_{ISAv1}Q^*$ capture the effect on marginal revenue when the ISA virus had the major effect on production, hence D_{ISAv1} is activated between February 2009 and July 2010 (see Figure 1). Note that the latter variable is activated after the variable D_IY because the ISA virus pandemic had a delayed effect on production. We expect that $\lambda+\lambda_{ISAv1}$ will be positive and less than or equal to one.

If our results indicate that $\lambda+\lambda_{ISAv1}$ is different from zero, to some extent we can say that there was room to exercise market power in this market for at least 18 months approximately (in a hypothetical scenario where Chilean farmers collude), which is the time that D_{ISAv1} is activated. It is not possible to know what happened after this period using this methodology. After July 2010, the Chilean producers started to recover, their production levels. Hence, information about what happened when a producer reduce their production for a period largest than 18 month is not available.

On the other hand, the potential effect on perceived revenue due to production recovery is captured by $D_{ISAv2}Q^*$, where D_{ISAv2} is activated between August 2010 and December 2012. We previously argued that accelerated recovery of Chilean production, which started in August 2010 (see Figure 1), may have been the cause of prices falling observed during 2011 to 2012. Hence, we expect that $\lambda+\lambda_{ISAv2}$ will be negative and greater than or equal to minus one. In this case, we are saying that the price faced by Chilean producers during recovery time was below to the average marginal cost, and that hence some producers had negative benefits during this period.

We assumed the following marginal cost function:

$$MC_t = \varphi_1 + \varphi_2 \ln Q_t + \varphi_3 \ln Feed_t + \varphi_R D_R \ln Q_t + \mu_t \tag{8}$$

where ln*Feed* represents the logarithm of the fish feeding cost. The export price of Chilean fishmeal is used in this case as a proxy variable, since the domestic production of fish meal is shared between domestic and foreign uses.[3] The interactive variable $D_R \ln Q$ is incorporated to capture the highest marginal cost per kilogram produced, due to the new regulations issued to prevent future sanitary episodes. D_R was activated from January 2013 and onwards[4]. We expect that φ_{Reg} will be different from zero and positive. We tried to include a measure of labor costs. However, because of the absence good salmon industry wage estimates, finally we excluded this variable from the estimations.

Finally, the supply function of the industry is obtained equating equation (7) with equation (8):

$$P_t = \varphi_1 + \varphi_2 \ln Q_t + \varphi_3 \ln Feed_t + \varphi_{Reg} D_R \ln Q_t - \left(\lambda + \lambda_{ISAv1} D_{ISAv1} + \lambda_{ISAv2} D_{ISAv2}\right) Q^*_t + \mu_t \tag{9}$$

Until now, the dynamic nature of the industry has not been considered in our empirical model. Short-run dynamics, generated by factors such as habit formation or adjustment costs, are inherent in a market like the salmon one.. Random shocks and seasonal shift may also cause short-run deviations from equilibrium. Moreover, the reactions of competitors are not instantaneously, so market power is probable in the short-run. As we mentioned above, to introduce dynamics in the model, a reformulation of the BL model using an ECM was proposed by Steen and Salvanes (1999).

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[3] Salmon diet included other component different from fish meal. The most important is soya meal. Due that the literature found that this two components can be considered strong substitutes (see Asche & Tveterås, 2004), we considered that fish meal price reflects in a good manner the behavior of salmon feed cost.

[4] The new regulation was implemented in April 2010 (Subsecretaria de Pesca, 2013). However, because D_{ISAv2} was activated until December 2012, multicollienarity could arise. Therefore, finally we decide to activate D_{Reg} from January 2013 onward.

Steen and Salvanes (1999) assumed that firms solved a succession of one-period problems. This ignores the dynamic optimization behavior of the industry, as the expectation of future variables is ignored (Perloff *et al.*, 2007). However, this procedure has the advantage of obtaining a much simpler model. Moreover, when we include dynamics through an ECM, we have the advantage of being able to distinguish market power or, in our case, to test whether the Chilean producers affect the price both in the long-run as in the short-run.

We rewritten the static demand equation (6) in a dynamic formulation. For this, we used an Autoregressive Distributed Lag (ADL) model. In this case, the dynamic demand equation becomes:

$$\begin{aligned}\ln Q_t = &\sum_{i=1}^{p}\delta_{Q,i}\ln Q_{t\text{-}i} + \sum_{i=0}^{k}\delta_{P,i}P_{t\text{-}i} + \sum_{i=0}^{k}\delta_{Z,i}Z1_{t\text{-}i} + \sum_{i=0}^{k}\delta_{Z,i}Z2_{t\text{-}i} \\ &+\sum_{i=0}^{k}\delta_{Y,i}Y_{t\text{-}i} + \sum_{i=0}^{k}\delta_{PZ,i}PZ2_{t\text{-}i} + \delta_{Image}D_I Y_{t-1} + \delta D + \varepsilon_t\end{aligned} \tag{10}$$

where D is a vector of deterministic variables which might include a constant or trend term and centered seasonal dummies. p and k are the maximum lag order (in levels) for the endogenous and exogenous variables, respectively. At the same way, the static supply equation (9) can be rewritten such as:

$$\begin{aligned}P_t = &\sum_{i=1}^{p}\varphi_{P,i}P_{t-i} + \sum_{i=0}^{k}\varphi_{Q,i}\ln Q_{t-i} + \sum_{i=0}^{k}\varphi_{Feed,i}\ln Feed_{t-i} - \sum_{i=0}^{k}\lambda_i Q^*_{t-i} \\ &-\left(\lambda_{ISAv1}D_{ISAv1} + \lambda_{ISAv2}D_{ISAv2}\right)Q^*_{t-1} + \varphi_{Reg}D_R\ln Q_{t-1} + \Phi D + \mu_t\end{aligned} \tag{11}$$

The ADL model was then rewritten as an ECM equation, based on Chang *et al.* (2012). The demand function became:

$$\begin{aligned}\Delta\ln Q_t = &\sum_{i=1}^{p-1}\alpha_{Q,i}\Delta\ln Q_{t\text{-}i} + \sum_{i=0}^{k\text{-}1}\alpha_{P,i}\Delta P_{t\text{-}i} + \sum_{i=0}^{k\text{-}1}\alpha_{Z,i}\Delta Z1_{t\text{-}i} + \sum_{i=0}^{k\text{-}1}\alpha_{Z,i}\Delta Z2_{t\text{-}i} + \sum_{i=0}^{k\text{-}1}\alpha_{Y,i}\Delta Y_{t\text{-}i} \\ &+\sum_{i=0}^{k\text{-}1}\alpha_{PZ2,i}\Delta PZ2_{t\text{-}i} + \Psi D + \gamma^*\begin{bmatrix}\ln Q_{t\text{-}1} - \theta_P P_{t\text{-}1} - \theta_{Z1}Z1_{t\text{-}1} - \theta_{Z2}Z2_{t\text{-}1} \\ -\theta_Y Y_{t\text{-}1} - \theta_{PZ2}PZ2_{t\text{-}1} - \theta_{Image}D_I Y_{t-1}\end{bmatrix} + \varepsilon_t\end{aligned} \tag{12}$$

where Δ denotes the first difference operator and the term in brackets is the error correction term. The coefficient of the error correction term, $\gamma^* = 1 - \Gamma_1$, represents the speed of adjustment towards the long-run equilibrium where $0 \leq \left|\sum_{i=1}^{p} \hat{\delta}_{Q,i}\right| = \Gamma_1 \leq 1$, and the lagged terms capture the short-run dynamics. The long-run parameters, θ_j, are obtained dividing $\sum_{i=1}^{k} \hat{\delta}_{j,i}$ ($\hat{\delta}_{j,i}$ are estimated in the ADL model) by γ^*, where $j = P, Z1, Z2, Y, PZ2, Image$.

On the other hand, the supply function in ECM form can be rewritten as:

$$\begin{aligned} \Delta P_t = {} & \sum_{i=1}^{k-1} \beta_{P,i} \Delta P_{t-i} + \sum_{i=0}^{k-1} \beta_{Q,i} \Delta \ln Q_{t-i} + \sum_{i=0}^{k-1} \beta_{Feed,i} \Delta \ln Feed_{t-i} - \sum_{i=0}^{k-1} \lambda_i \Delta Q^*_{t-i} + \Phi D \\ & + \psi^* \begin{bmatrix} P_{t-1} - \xi_Q \ln Q_{t-1} - \xi_{Feed} \ln Feed_{t-1} - \xi_{Reg} D_R \ln Q_{t-1} \\ -(\Lambda + \Lambda_{ISAv1} D_{ISAv1} + \Lambda_{ISAv2} D_{ISAv2}) Q^*_{t-1} \end{bmatrix} + \mu_t \end{aligned} \tag{13}$$

where $\psi^* = 1 - \Omega_1$ represents the speed of adjustment towards the long-run equilibrium, where $0 \leq \left|\sum_{i=1}^{p} \hat{\varphi}_{P,i}\right| = \Omega_1 \leq 1$. The long-run parameters are obtained dividing $\sum_{i=1}^{k} \hat{\varphi}_{j,i}$ ($\hat{\varphi}_{j,i}$ are estimated in the ADL model) by ψ^*, where $j = Q, Feed, Reg$. Λ is obtained dividing $\sum_{i=1}^{k} \hat{\lambda}_i$ ($\hat{\lambda}_i$ are estimated in the ADL model) by ψ^*, while Λ_{ISAv1} and Λ_{ISAv2} are obtained dividing λ_{ISAv1} and λ_{ISAv1} estimated in the ADL model by ψ^*.

The parameter Λ captures the effect that the Chilean producers exert on the price in the long-run. We expect that Λ will be equal to zero because the salmon industry should be competitive in the long run. Moreover, we also considered that the market would be relatively stable, except for the ISA virus period. Therefore, price should equal marginal cost in the long-run. In the case of the parameters that capture market power in the short-run, the λ_i*'s*, we expected them to be different from zero. As we have argued above, salmon producers in other countries cannot react instantaneously to changes in the market. Hence, the capability to substitute Chilean production in the short-run must have been limited.

Prior to estimating the system, it was necessary to identify the integration order of the variables. If all variables were found to be *I(0)*, then conventional estimation procedures could be used and an ECM approach would not be necessary.

We used the estimated coefficients from the ADL models to obtain the long-run parameters. Therefore, it was required to estimate the system composed by equations (10) and (11) first. Moreover, we made a preliminary estimation round to create the variable Q^*. For the latter, we used the long-run estimated demand coefficients. To deal with potential endogeneity problems we used the Three Stage Least Square (3SLS) procedure to estimate the ADL models simultaneously.

Once we obtained the long-run parameters we computed the error correction terms for both demand and supply relations. Then, we used them to estimate the system formed by the ECM equations. The error correction term computed with the long-run parameters for demand was included in equation (12), while the error correction term computed with the long-run parameters for supply is included in equation (13).

However, before estimating the ECM equations, it was necessary to test if the estimated long-run parameters for demand and supply equations cointegrated. We performed the bound test for cointegration (Pesaran *et al.*, 2001) for the single equation approach, and the Johansen’s multivariate cointegration test (Johansen, 1988). The Johansen’s test is useful to determine if there is more than one cointegrated vector in the system, in which case the single equation approach can be misleading (Harris, 1995).

c. Data

We considered a monthly data base, which covers from January 2001 to December 2013. This gave us time series of 156 observations to estimate our empirical model. We consider this period because in 2001 Chilean salmon production represented 25% of the global Atlantic salmon production and this share remained stable until the ISA virus crisis (FAO, n.d.). Moreover, from 2001 Chilean Atlantic salmon represented more than 50% of all Atlantic salmon imports to the US (Fisheries Statistics and Economics Division, 2014). Hence, it could be argued that since 2001 the Chilean salmon industry became the main exporter of Atlantic salmon to the US and an important producer in the global salmon market.

As mentioned in the previous subsection, our endogenous variables were the import price and the quantity imported of Chilean Atlantic salmon in the US market. We also used the price of the Canadian Atlantic salmon imported by the US and the US Pacific salmon export price (FOB) as substitute prices. To compute the latter, a quantity weighted export price for the different Pacific salmon species (Chinook, Chum, Pink, Coho and Sockeye) was calculated. We assumed that price arbitrage works, so that the domestic prices tended to converge to export prices. Export and import data was obtained from the National Marine Fisheries Service (NMFS) division of the National Oceanic and Atmospheric Administration (NOAA) in the US.

TABLE 1. Summary statistics (January 2001 – December 2013)

Variable	Unit	Nº	Mean	σ	Min	Max
Chilean Atlantic salmon import price (P)	US$/kg	156	7.22	2.39	3.20	11.96
Chilean Atlantic salmon import quantity (Q)	M Tons	156	7.41	2.26	1.70	10.72
Canadian Atlantic salmon import price ($Z1$)	US$/kg	156	5.87	0.71	4.89	8.26
US Pacific salmon export price ($Z2$)	US$/kg	156	3.51	0.54	2.31	5.18
US personal consumption (Y)	T US$	156	9.36	1.36	7.01	11.69
Chilean fishmeal export price ($Feed$)	US$/kg	156	1.04	0.41	0.44	1.87

Note: M = Millions; T = Trillions; σ = Standard deviation; Min = minimum value; Max = Maximum value.

Source: NMFS, US Department of Commerce and Chilean Superintendent's Office of Customs.

For the demand equation, in addition to the prices of substitutes, we also used US Personal Consumption Expenditures (PCE) as an explanatory variable. This variable is a proxy for income, and was obtained from the Bureau of Economic Analysis of the US Department of Commerce. For the supply relation, we used the Chilean fishmeal export price as a proxy for feed costs. The latter was obtained from the Chilean Superintendent's Office of Customs. Table 1 shows the summary statistics of the data.

4. Results

To test for stationarity, we used the Augmented Dickey-Fuller (ADF) test (Dickey & Fuller, 1981). In Table 2 we present the results in levels and in first difference for the period January 2001 - December 2013. These results include a constant term and seasonal dummies as deterministic variables, and the optimum lag length was selected with the Akaike Information Criterion (AIC). According to the ADF test, we could reject stationarity for all variables in levels, except for *Z2*, while when we tested for stationarity in first differences, the null hypothesis of unitary root was rejected in all cases at very low significance levels. This suggest that all variables are *I(1)*, except *Z2* which would be *I(0)*. The latter is not necessarily a problem for the estimation of the ECM, since variables integrated of different orders, can still be cointegrated.

TABLE 2. Augmented Dickey-Fuller Tests for Unit-Root (with Constant)

Variables	Test statistic in Levels	Test statistic in Differenced
lnQ	-1.28(2)	-4.58(4)***
P	-0.89(1)	-7.93(0)***
Y	-0.52(3)	-5.35(2)***
Z1	-1.69(1)	-8.66(0)***
Z2	-3.13(0)**	-10.54(2)***
PZ2	-1.38(1)	-8.70(1)***
lnFeed	-1.52(1)	-8.99(0)***

Note: Numbers in parentheses indicate the number of lags chosen by the Akaike Information Criterion (AIC); H_0 of Non-stationarity; *** Significance at 1% levels; ** Significance at 5% levels.

To determine the optimal lag order and the introduction of non-stochastic components in the model we estimated different models. We used different specification for the non-stochastic components of the demand and supply equations: with a constant; with a constant restricted to the cointegration space; with a trend restricted to the cointegration space. To decide which variable is included in the model, we use a theoretical criteria (negative price elasticity; non-negative income elasticity; the absolute value of Λ less than one). We found a restricted trend in the demand equation and a restricted constant in the supply relation working well. In addition, we included three impulse dummies in December 2012 ($d1$), July 2011 ($d2$) and August 2012 ($d3$) to take care of outliers in the supply equation. The lag order was selected using the Akaike Information Criterion (AIC). Considering the degrees of freedom of the model, we tested from a maximum lag order of five lags in levels for the exogenous and endogenous variables. We found that two lag in levels for the endogenous variables (therefore, one lag in ECM) was the optimum, independently of the lag order selected for the exogenous variables. Finally, we decided to use five lag in levels for the exogenous variables and two lag in levels for the endogenous variables.

We were especially concerned with the potential multicollinearity that could arise with the introduction of the interactive variables in the model. Therefore, we decided to estimate a base model first that excluded these interactive variables, and then include gradually the interactive variables and checked for stability in the parameters of the base model. Moreover, we estimate the model restricting the long-run parameter Λ to zero as a way to identify a possible collinearity problem with Λ_{ISAv1} and Λ_{ISAv2}. In all cases, the results obtained remained stable. Hence, the final specification included all the variables used in equations (12) and (13).

TABLE 3. Bound test for cointegration

Equation	χ^2	90% confidence		95% confidence		99% confidence	
		Lower	Upper	Lower	Upper	Lower	Upper
Demand	22.41	18.64	26.00	21.04	28.96	26.16	35.12
Supply	32.77	15.92	23.52	18.16	26.24	23.04	31.92

Note: If the test statistic lies between the bounds, the test is inconclusive. If it is above the upper bound, the null hypothesis of no cointegration is rejected. If it is the below the lower bound, the null hypothesis of no cointegration cannot be rejected. Critical values obtained from Pesaran et al. (2001).

As we mentioned in the previous section, we estimated the ADL models first and then we computed the long-run parameters. The standard errors for the long-run parameters were calculated using the Delta Method. After the previous procedure, we were able to test for cointegration. For this we use the bound test for cointegration based on Pesaran *et al.* (2001). For the demand relation, the null hypothesis was H_0: $\gamma^* = \gamma^*\theta_P = \gamma^*\theta_{Z1} = \gamma^*\theta_{Z2} = \gamma^*\theta_Y = \gamma^*\theta_{PZ2} = \gamma^*\theta_{Image} = 0$; while for the supply relation it was H_0: $\psi^* = \psi^*\theta_Q = \psi^*\theta_{Feed} = \psi^*\theta_{Reg} = \psi^*\Lambda = \psi^*\Lambda_{ISAv1} = \psi^*\Lambda_{ISAv2} = 0$. The results for this test are presented in Table 3.

According to the bound test for cointegration, is not possible to reject the existence of a long-run relationship in the supply equation. The Wald statistic is higher than the upper bound with 99% of confidence. On the other hand, for demand function the test is inconclusive. The Wald statistic is higher than the lower bound with 90% and with 95% of confidence, but less than the upper bound in all cases.

We also tested for cointegration using the reduced rank test of Johansen (1988). This is a maximum likelihood test on the results from a vector autoregression (VAR). In this case, the null hypothesis is that there are *r* or fewer cointegrating equations in the system, where *r* is the maximum rank. Table 4 show the results for this test.

TABLE 4. Multivariate cointegration test of Johansen

Equation		Maximum Rank (*r*)					
		0	1	2	3	4	5
Demand	Trace statistic	120.78	80.21*	47.87	19.04	5.72	1.66
	Critical value	114.90	87.31	62.99	42.44	25.32	12.25
Supply	Trace statistic	55.48	22.57*	5.57	1.78		
	Critical value	53.12	34.91	19.96	9.42		

H_o: There are *r* or fewer cointegrating equations in the system.

TABLE 5. Three Stage Least Square (3SLS) estimates of the Parsimonious ECM models

Demand function			Supply function		
Coefficient	Estimate	*p*-value	Coefficient	Estimate	*p*-value
$\alpha_{lnQ,1}$	-0.2194	0.001	$\beta_{P,1}$	0.3028	0.000
$\alpha_{P,0}$	-0.2122	0.000	$\beta_{lnQ,2}$	0.4903	0.000
$\alpha_{P,3}$	-0.0515	0.117	$\beta_{lnQ,3}$	0.3098	0.005
$\alpha_{Z1,0}$	0.2544	0.000	$\beta_{lnQ,4}$	-0.2640	0.025
$\alpha_{Z1,1}$	-0.0743	0.116	$\beta_{lnFeed,0}$	0.9281	0.004
$\alpha_{Z1,4}$	0.1112	0.014	$\beta_{lnFeed,1}$	0.6042	0.057
$\alpha_{Z2,1}$	0.1384	0.007	$\beta_{lnFeed,3}$	-0.8559	0.005
$\alpha_{Z2,3}$	0.0436	0.077	λ_1	0.0280	0.003
$\alpha_{PZ2,0}$	0.0050	0.133	λ_3	0.0294	0.008
$\alpha_{PZ2,1}$	-0.0104	0.085	λ_4	0.0518	0.000
$\alpha_{PZ2,2}$	0.0088	0.004	*July*	-0.0956	0.081
$\alpha_{PZ2,4}$	-0.0051	0.064	*August*	-0.0870	0.112
February	-0.0623	0.058	*October*	-0.2290	0.000
March	0.1093	0.001	*d1*	1.2137	0.000
August	0.0732	0.048	*d2*	-1.0152	0.000
September	-0.0564	0.140	*d3*	-0.6431	0.000
Constant	2.0033	0.000	ψ^*	-0.0706	0.000
γ^*	-0.2081	0.000			
			Long-run parameters		
Long-run parameters			ξ_{lnQ}	0.3248	0.798
θ_P	-0.7713	0.003	ξ_{lnFeed}	6.3541	0.000
θ_Y	1.2877	0.000	ξ_{Reg}	1.3843	0.097
θ_{Z1}	0.4098	0.003	$\xi_{lnQ}+\xi_{Reg}$	1.7091	0.275
θ_{Z2}	-1.0643	0.059	Λ	-0.1638	0.713
θ_{PZ2}	0.1337	0.057	Λ_{ISAv1}	0.5113	0.202
θ_{Image}	-0.0374	0.003	Λ_{ISAv2}	-0.2579	0.302
Trend	-0.0284	0.000	$\Lambda+\Lambda_{ISAv1}$	0.3474	0.511
			$\Lambda+\Lambda_{ISAv2}$	-0.4217	0.216
Long-run demand elasticity			*Constant*	7.6783	0.005
ε_{PP}	-2.1839	0.000			
ε_{YY}	12.0532	0.000			
ε_{PZ1}	2.4068	0.003			
ε_{PZ2}	-0.3427	0.632			
$\varepsilon_{YY}+\varepsilon_{Image}$	11.7034	0.000			

Note: Standard errors for long-run parameters used to obtain *p*-values are calculated using the Delta Method.

The results for the Johansen test for cointegration suggested that there was only one cointegrating equation for each relation. The trace statistics, computed for both the demand and supply relations was lower than the critical value when $r = 1$. Hence it was not possible to reject that there was one or fewer cointegrating equations in the system in both cases. Moreover, in both cases it was possible to reject the null hypothesis that $r = 0$.

The evidence obtained from both cointegration tests suggested that there existed one long-run relationship between variables for both the demand and supply functions. Thus, we were able to estimate simultaneously an ECM system formed by equations (12) and (13).

We tested for parsimonious versions of the ECM models (PECM). We ended with small models, where a likelihood ratio test for 35 excluded variables (in both equations jointly) was not rejected. The likelihood ratio statistic was 31.33, with a *p*-value of 0.6459. The results for the parsimonious models are presented in Table 5.

We carried out specifications tests for normality, autocorrelation and heteroskedasticity. The results for these tests are presented in Table 6. In general, all tests suggested that the residuals, of the demand and supply ECM equations, comply with white noise errors. Nevertheless, at the 90% level of confidence, the ARCH-LM test with eight lags could not reject heteroskedasticity for the residuals of the demand equation. However, with higher lag order the problem did not persist.

TABLE 6. Specification test for normality, autocorrelation and heteroskedasticity

Residuals		Skewness & Kurtosis test	Portmanteau test			ARCH-LM test		
			8 lags	10 lags	12 lags	8 lags	10 lags	12 lags
Demand	Statistic	4.49	1.389	3.932	17.232	14.136	14.763	16.461
	p-value	0.106	0.994	0.950	0.141	0.078	0.141	0.171
Supply	Statistic	1.75	5.668	5.826	6.420	2.326	2.274	5.462
	p-value	0.417	0.684	0.830	0.893	0.970	0.994	0.941

Note: H_0 of normality for the Skewness & Kurtosis test; H_0 of non-autocorrelation for the Portmanteau test; H_0 of non-autocorrelation for the Portmanteau test; Skewness & Kurtosis test implements the method described by D'Agostino *et al.* (1990) with the empirical correction developed by Royston (1991).

The results presented in Table 5 show that the adjustment parameters (γ^*, ψ^*) comply with the condition that they must be negative. Moreover, other conditions must be fulfilled to be sure about the model specification is adequate. First, the long-run parameter for *PZ2* must be significant, as a way to identify the parameters Λ and λ's in the supply relation. Second, the parameters Λ and λ's must be in their theoretical range of minus one to one. The results show that the estimated long-run parameter for *PZ2* was significant at 94% level of confidence, while the parameters Λ and λ's were all in their theoretical ranges, although not all statistically significant.

Using the estimated parameters of the model, we can study how long does it take for the market to fully adjust to the long-run equilibrium when it faces a market shock. For the demand we used the parameter associated with the error correction term, γ^*, which measures the instantaneous adjustment to the long-run equilibrium, and the dynamic multipliers obtained from the ADL model estimation (not presented here).

TABLE 7. Adjustment to the long-run equilibrium

Equation	Months	Adjustment	Accumulative Adjustment
Demand	1	0.2081	0.2081
	2	0.3249	0.5330
	3	0.3606	0.8936
	4	0.3606	1.2541
Supply	1	0.0706	0.0706
	2	0.1540	0.2246
	3	0.1371	0.3617
	4	0.1371	0.4988
	5	0.1371	0.6358
	6	0.1371	0.7729
	7	0.1371	0.9100
	8	0.1371	1.0471

Note: The ADL estimated coefficients are: $\delta_{Q,1} = 0.56126$; $\delta_{Q,2} = 0.17137$; $\varphi_{P,1} = 1.18160$; $\varphi_{P,2} = -0.24006$

According to Asche (1997a), the dynamic multipliers can be interpreted as the adjustment that takes place *i* periods after the deviation from the long-run equilibrium. In the demand equation, ln*Q* is the dependent variable, hence $\delta_{Q,i}$ was used to capture the adjustment of the demand over the time. In i=1 the parameter $\delta_{Q,1}$ captures the whole effect on demand in t-1, and so on (see Asche, 1997a). The maximum value that i can take was two in our case. For the supply the same methodology was used, but here we considered the parameter associated with the error correction term, ψ^* and the short-run parameters $\varphi_{P,i}$ obtained from the ADL model.

The idea is that in the first month both demand and supply equations are adjusted only by their adjustment parameter γ^* and ψ*, respectively, when a market shock takes place. In the next month, in $t+1$, both equation are adjusted by their adjustment parameters too, and also the dynamic multipliers adjust the equation based in the result obtained in the previous month. Hence, for $t+1$ the adjustment to the long-run equilibrium is $\gamma^*+\delta_{Q,1}\ \gamma^*$ for the demand equation and $\psi^*+\varphi_{P,1}\ \psi^*$ for the supply equation. The same method is used to obtain the adjustment in $t+2$. Moreover, from $t+3$ onwards, due that we only have two lags in levels for the endogenous terms, the adjustment is the same as in $t+2$. Table 7 shows the results of the adjustment calculations made for the demand and supply equation.

The demand equation adjusts more quickly to the long-run equilibrium than the supply equation. Between three and four month takes the adjustment to the long-run equilibrium by the demand side. In constrast, the supply takes approximately between seven and eight months to adjust to the long-run equilibrium.

Finally, as a way to understand how price are determined in the long-run, we solved the system composed by the supply and demand equations in the long-run. After some algebra, we obtained the following reduced from equation for price determination (the details of the derivation are described in Appendix B):

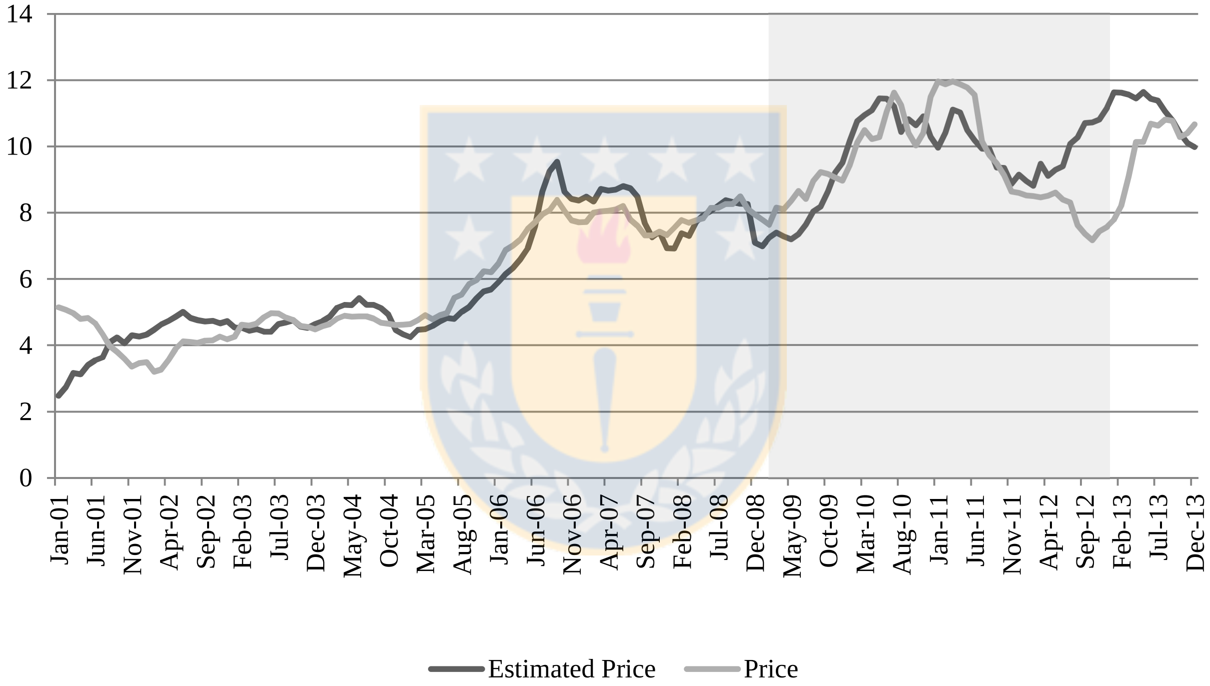
$$P_t = \frac{-1}{\left(\xi_{\ln Q} + \xi_{Reg} D_R\right)\left(\theta_P + \theta_{PZ_2} Z2_t\right) - 1} \begin{bmatrix} \xi_0 + \xi_{Feed} \ln Feed_t - \begin{pmatrix} \Lambda + \Lambda_{ISAv1} D_{ISAv1} \\ +\Lambda_{ISAv2} D_{ISAv2} \end{pmatrix} Q_t^* \\ +\left(\xi_{\ln Q} + \xi_{Reg} D_R\right) \begin{pmatrix} \theta_{Z1} Z1_t + \theta_{Z2} Z2 + \theta_Y Y_t \\ +\theta_{Image} D_I Y_t + Trend_t \end{pmatrix} \end{bmatrix}$$

If we consider that ξ_{lnQ}, $\xi_{lnQ}+\xi_{Reg}$, Λ, $\Lambda+\Lambda_{ISAv1}$ and $\Lambda+\Lambda_{ISAv2}$ are not significant, we can rewrite the latter equation as:

$$P_t = \xi_0 + \xi_{Feed} \ln Feed_t \tag{14}$$

According to equation (14), in the long-run the import price of Chilean Atlantic salmon marketed in the US depended solely on the export price of Chilean fishmeal. Figure 3 shows the estimated price obtained using the equation (14) versus the import price of Chilean Atlantic salmon in the US market.

FIGURE 3. Actual and Estimated import price of Chilean Atlantic salmon in the US market January 2001 December 2013. The left hand axis measures prices per kilogram (US$/kg). The shaded area represent the ISA virus crisis period. *Source*: NMFS.



5. Discussion

The results obtained for the long-run parameters for equation (12) comply with the economic theory of demand (Table 5). The long-run price elasticity is negative, while the long-run income elasticity as well as the long-run cross price elasticity of Canadian Atlantic salmon are positive and significant. The previous result confirms that the Canadian Atlantic salmon is a substitute of Chilean Atlantic salmon. However, the cross elasticity is different from one, therefore, this indicate that the Canadian Atlantic salmon is not a perfect substitute of Chilean Atlantic salmon. As mentioned earlier, the Canadian salmon is sold principally as round salmon, which probably implies that the production of Canadian farmers targets a different market segment (Asche & Bjørndal, 2011).

We obtained a high income elasticity for Chilean Atlantic salmon, confirming the reputation of salmon as a luxury good. It is interesting to note that in the short-run income has no effect on demand. This means that an income variation does not affect instantaneously the demand for Atlantic salmon from Chile.

In the case of the long-run cross price elasticity of Pacific salmon, this is not significant. This means that the US Pacific salmon is not a substitute for Chilean Atlantic salmon in the US market in the long run. It seems that the degree of differentiation between these products is high.

Finally, the results show that the income elasticity of demand fell during the ISA virus crisis, probably due to the negative impact of the crisis on the image of Chilean salmon. The long-run income elasticity decreased from 12.1 to 11.7, which indicates that the willingness to pay by consumers was lower during the crisis. This is probably because the consumers learned about the lack of sanitary controls in Chilean farms and the high use of antibiotics to control the disease, during the crisis among other issues

For the supply equation, we obtained that the supply curve is infinitely elastic in the long-run. Meanwhile, for the short-run we obtained a positive slope for the supply curve, which complies with increasing marginal cost.

A significant coefficient was obtained for the regulatory variable (at the 90% level of confidence). However, to analyze its total effect it is necessary to evaluate the sum of the coefficients of ln$Q$ and the interactive variable $D_R$ln$Q$. That is, our interest is to analyze if the long-run slope of supply curve change after the crisis due to the new regulation. Due that $\xi_{lnQ}+\xi_{Reg}$ is non-significantly different from zero, the regulation don't have an effect on the long-run slope of supply after the crisis.

However, we need to be careful about the previous result. D_R is activated for only one year, since January 2013. Exactly one month after the industry completely recovers from the crisis. Then, it is probably that the regulation has an effect only when the industry operates at full capacity, and this effect will be reflected years later. Then, the effect on cost is not possible to detect using our data sample. Another explanation for the result is that due to the regulation, Chilean farmers could have improved their efficiency. Therefore, a non-significant coefficient for regulation is obtained because the effect on efficiency countering the effect on production costs.

The long-run parameter that captures the effect on price that the Chilean producers exert in the long-run, Λ, is not significant. This confirms our hypothesis that the Chilean salmon industry moves in a competitive environment. Moreover, it is very common to hear among Chilean salmon producers that the high price of Atlantic salmon observed during the ISA virus crisis was due to the lower production of salmon in Chile. We found that the lower production of Chilean farmers as well as the greater offer of Atlantic salmon during the recovery time had no effect on price in the long run. The coefficient $\Lambda+\Lambda_{ISAv1}$ and the coefficient $\Lambda+\Lambda_{ISAv2}$ are both non-significant. Hence, this results suggest that the increase in prices and its consequent fall observed during the sanitary crisis was not due to a change in the amount offered of Atlantic salmon by Chilean farmers, but rather due to another reasons.

According to equation (14), in the long-run the import price of Chilean Atlantic salmon depends mainly on feed cost prices. Specifically, in our model, it depends on the export price of Chilean fishmeal, while the explanatory demand variables have no effect in the long-run, since the supply curve is flat. The export price of Chilean fishmeal is transmitted to market price through factor markets. The result seem intuitive. Feeding is the most important component of total production costs in the salmon industry, achieving more than 50% of the salmon farmers costs (see Asche & Bjørndal, 2011). Moreover, this result was predicted by Guttormsen (2002) over a decade ago. Guttormsen (2002) found that feed has zero substitution possibilities and, therefore, he concluded that salmon prices in the future could become even more dependent on feed prices. Asche and Bjørndal (2011) also obtain this result based on the strong correlation that they observe between production cost and salmon price over time. They mention that the strong correlation suggest that production cost is the main factor that determine the price, while demand determine how much salmon is produced. Moreover, they mention that the production process is becoming more feed intensive.

Figure 3 shows the estimated price obtained using the estimated equation versus the actual import price of Chilean Atlantic salmon in the US market. At first sight, the estimated price moves very similar to realist actual value. Specifically, during the ISA virus period, 2008 -2010, the model tracks remarkably well the actual salmon price. Nevertheless, at the end of the sample period the model fails to accurately predict the actual import price of Chilean Atlantic salmon. It is probably that short-run dynamics are behind this imbalance on price. As already discussed, the effect of a demand shock lasts for a period between three and four months, while the effect of a supply shock is maintained during a period of seven to eight months.

Moreover, we found that, alike Steen and Salvanes (1999), there is market power in the short-run. Hence, the quantity supplied by Chilean Atlantic salmon producers has a short-run effect on price. Because the adjustment to the long-run equilibrium by supply side is slow, it is probable that market power exerted in the short-run could be important for price determination.

Considering the imbalance that we see in Figure 3, the evidence of market power in the short-run could imply that the rapid recovery of Atlantic salmon production after the sanitary crisis did had an effect on price (setting a price below marginal cost). Nevertheless, that effect is not for the whole recovery period, but rather when the short-run market power from past periods were being accumulated. The recovery period lasted more than two years with a constant upward trend. This leaves no space for an adjustment to the long-run equilibrium. Moreover, an accumulative effect of two years exerting short-run market power constantly could be significant, although the coefficients estimated for λ's are small.

It is important to note that a same process for recovery period is not observed for the period when the ISA virus had a several effect on production. It seems more likely to increase the production by a producer with idle capacity than to reduce the supply when the production decision is already taken, although an overshooting in production is imminent. Moreover, high prices encourage producers to stay in the market, as well as the opportunity to obtain market share. During the crisis the prices were increasing, hence new producers have incentive to enter to the market. However, during the recovery price remains high, so out of the market is not a good option. Finally, a reduced demand during the subprime crisis could have counterbalanced the effect of a lower supply of Chilean Atlantic salmon during the crisis. Therefore, for that period there is no an accumulative effect of short-run market power.

If we consider the whole sample, the recovery could be considered as an isolated event. Since mid-2013 the estimated price and their real value converge once again. Moreover, as we argue before, most of the time that the sanitary crisis lasts the estimated price moves very similar to their real value. This means that the price variations observed during the crisis, without considering the final period of the recovery, were only a response to the variations on production cost, principally feeding costs, which salmon producers were faced.

Therefore, the results suggest that, in general, Norwegian producer as well as other salmon-producing countries reacted appropriately to the lower production of Atlantic salmon in Chile and to the global economic context during the crisis. Then, the regulatory authority has no need to be worried about a possible collusive behavior in the future. The only way to exert market power is when the major producers of Atlantic salmon collude, and still the non-competitive outcome cannot be maintained in the future because other potential salmon-producing countries might consider profitable to enter.

The result that fishmeal price leading the import price of Chilean Atlantic salmon in the long-run is an interesting results because makes us wonder what is really behind on price determination process. Fishmeal and the other feed components are not exogenous to the recently general food price trend due its relation with general commodities. Climate change, the bio-fuel revolution, crude oil price, wild fish stocks or the economic growth, among others, are factors which affect the price in commodity market. Therefore, this variables also affects fishmeal price as well as the price of the other feed components. This could explain the large variation on price observed during the ISA virus crisis. By coincidence, the sanitary crisis arised in the same period when the global food crisis happened.

However, it is important to mention that the results are valid only for the US. If we compare the behavior of Atlantic salmon price between US and EU markets, the relation is not so strong (Asche & Bjørndal, 2011). Moreover, the high price observed during the ISA virus period, which according to our results is associated with high fishmeal prices, is not observed in the EU market. Due that the EU markets are dominated mainly by Norwegian salmon while the US market is dominated mainly by Chilean and Canadian salmon, probably differences in productivity (see *e.g.* Asche & Bjørndal, 2011) and cost structure (see *e.g.* Bjørndal, 2002) could explain this prices differences between markets. The impact of a change in fishmeal price is different for Norwegian producers than for Chilean producers. However, due that Norwegian producers compete with a little amount of Atlantic salmon in the US, in the long-run some effect could be observed in the EU salmon price due to price arbitrage if the market shock is maintained for a long-period.

Turning back to our research, it appears that in the future feeding cost will grow. This can happen, as an example, due to the over-exploiting of fishery resources, the negative effect of global warming in agriculture, or the higher global demand for food, among others. Therefore, if we really want that the aquaculture could be a real feeding option for global population and thereby relieving the pressure on agriculture or fishing, it is important to maintain the rates of productivity growth observed in the last decades as a way to reduce the market price in the long-run (see *e.g.* Asche, 1997b; Asche 2008). According to Asche and Bjørndal (2011), it may still be possible to reduce production costs if other factors are exploited even more efficiently.

6. Conclusions

To analyze the functioning of the Atlantic salmon market in the US, a Steen and Salvanes (1999) extension of the Bresnahan-Lau model was successfully estimated for the Chilean industry. We found that the variables considered in the long-run relations for both demand and supply equations were cointegrated. Moreover, the estimated long-run parameters comply with economic theory and with the theoretical restrictions imposed by the used framework. Parsimonious versions of the ECM were estimated and the specification tests suggest that the models for both demand and supply relations are well specified. In other words, the models were a good approximation to the data generation process.

The main findings indicate that, in an imbalance scenario such as the ISA virus crisis, the market remains competitive. Nevertheless, due that in the short-run there is some evidence of market power, it appears that during the recovery period the great offer of Atlantic salmon could have had an effect on price through the accumulated exercise of short-run market power. At the end, our results show that in the long-run the import price of Chilean Atlantic salmon is mainly determined by the fishmeal price, which affects the system through production costs, and this does not change significantly during the crisis. Meanwhile, the demand side has no effect on price because the supply curve is infinitely elastic in the long-run.

Appendix A

The inverse demand function for equation (6) is the following:

$$
\begin{aligned}
P_t = & \frac{-\delta_0}{\delta_1 + \delta_5 Z2_t} + \frac{1}{\delta_1 + \delta_5 Z2_t} \ln Q_t - \frac{\delta_2}{\delta_1 + \delta_5 Z2_t} Z1_t - \frac{\delta_3}{\delta_1 + \delta_5 Z2_t} Z2_t \\
& - \frac{\delta_4}{\delta_1 + \delta_5 Z2_t} Y_t - \frac{\delta_{Image}}{\delta_1 + \delta_5 Z2_t} D_I Y_t + \frac{-\varepsilon_t}{\delta_1 + \delta_5 Z2_t}
\end{aligned}
\tag{15}
$$

Then, the derivate of *P* with respect to *Q* is:

$$
\frac{\partial P_t}{\partial Q_t} = \frac{\partial D^{-1}(Q_t, Z_t; \delta)}{\partial Q_t} = \frac{1}{Q\left(\delta_1 + \delta_5 Z2_t\right)} \tag{16}
$$

Therefore, according to the equation (4), the perceived marginal cost could be rewritten as:

$$
PMR(\lambda) = P + \lambda \frac{Q}{Q\left(\delta_1 + \delta_5 Z2_t\right)} = P + \lambda Q^* \tag{17}
$$

where $Q^* = 1 \big/ \left(\delta_1 + \delta_5 Z2_t\right)$.

Appendix B

The long-run relation for the supply can be rewriting as the following:

$$\ln Q_t = \frac{1}{\xi_{\ln Q} + \xi_{Reg} D_R}\left[P_t - \left(\xi_0 + \xi_{Feed} \ln Feed_t - \left(\Lambda + \Lambda_{ISAv1} D_{ISAv1} + \Lambda_{ISAv2} D_{ISAv2}\right) Q_t^*\right)\right] \quad (18)$$

Equals with the long-run relation for the demand, the following equation is obtained:

$$\left(\begin{array}{l} \theta_P P_t + \theta_{Z1} Z1_t + \theta_{Z2} Z2 + \theta_Y Y_t \\ +\theta_{PZ2} PZ2 + \theta_{Image} D_I Y_t + Trend_t \end{array}\right) = \frac{1}{\xi_{\ln Q} + \xi_{Reg} D_R}\left[P_t - \left(\begin{array}{l} \xi_0 + \xi_{Feed} \ln Feed_t \\ -\left(\begin{array}{l} \Lambda + \Lambda_{ISAv1} D_{ISAv1} \\ +\Lambda_{ISAv2} D_{ISAv2} \end{array}\right) Q_t^* \end{array}\right)\right] \quad (19)$$

Solving the equation (19) for *P*:

$$P_t\left(\theta_P + \theta_{PZ2} Z2_t\right) = \frac{1}{\varsigma}\left[P_t - \left(\xi_0 + \xi_{Feed} \ln Feed_t - \left(\begin{array}{l} \Lambda + \Lambda_{ISAv1} D_{ISAv1} \\ +\Lambda_{ISAv2} D_{ISAv2} \end{array}\right) Q_t^*\right)\right] - \left(\begin{array}{l} \theta_{Z1} Z1_t + \theta_{Z2} Z2 + \theta_Y Y_t \\ +\theta_{Image} D_I Y_t + Trend_t \end{array}\right)$$

$$P_t\left(\theta_P + \theta_{PZ2} Z2_t - \frac{1}{\varsigma}\right) = \frac{-1}{\varsigma}\left(\xi_0 + \xi_{Feed} \ln Feed_t - \left(\begin{array}{l} \Lambda + \Lambda_{ISAv1} D_{ISAv1} \\ +\Lambda_{ISAv2} D_{ISAv2} \end{array}\right) Q_t^*\right) - \left(\begin{array}{l} \theta_{Z1} Z1_t + \theta_{Z2} Z2 + \theta_Y Y_t \\ +\theta_{Image} D_I Y_t + Trend_t \end{array}\right)$$

$$P_t = \frac{-1}{\varsigma\left(\theta_P + \theta_{PZ2} Z2_t\right) - 1}\left(\xi_0 + \xi_{Feed} \ln Feed_t - \left(\begin{array}{l} \Lambda + \Lambda_{ISAv1} D_{ISAv1} \\ +\Lambda_{ISAv2} D_{ISAv2} \end{array}\right) Q_t^* + \varsigma\left(\begin{array}{l} \theta_{Z1} Z1_t + \theta_{Z2} Z2 + \theta_Y Y_t \\ +\theta_{Image} D_I Y_t + Trend_t \end{array}\right)\right)$$

where $\varsigma = \xi_{\ln Q} + \xi_{Reg} D_R$. Therefore, the solution for *P* is:

$$P_t = \frac{-1}{\left(\xi_{\ln Q} + \xi_{Reg} D_R\right)\left(\theta_P + \theta_{PZ2} Z2_t\right) - 1}\left[\begin{array}{l} \xi_0 + \xi_{Feed} \ln Feed_t - \left(\begin{array}{l} \Lambda + \Lambda_{ISAv1} D_{ISAv1} \\ +\Lambda_{ISAv2} D_{ISAv2} \end{array}\right) Q_t^* \\ +\left(\xi_{\ln Q} + \xi_{Reg} D_R\right)\left(\begin{array}{l} \theta_{Z1} Z1_t + \theta_{Z2} Z2 + \theta_Y Y_t \\ +\theta_{Image} D_I Y_t + trend_t \end{array}\right) \end{array}\right] \quad (20)$$

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