

## Appendices

### Appendix 1. Barriers to Entry in the Chilean Seabass Industry

There are significant barriers to entry in this fishery due to fixed sunk costs, both in harvesting and international marketing. Vessels in this fishery are capital intensive and primarily sunk cost. They use species-specific gears and are subject to very tight entry regulations in Chile and other parts of the world (Bravo 2001). Thus, vessels operating in Chile's EEZ face similar entry restrictions if they wish to work in other fishing grounds of comparable commercial value.

Another barrier to entry arises from the minimum efficient scale of operation in this industry. Most of Chile's seabass production is export-oriented. This business typically requires (a) performing fishing operations diversified into several whitefish species (to deal with commercial portfolio risks) and (b) country-specific investments (fixed sunk cost) to create marketing networks to and within export markets. Both (a) and (b) demand deployment periods at which suppliers (vessel operators, processors, and exporters) can gain the trust of wholesalers in end-consumer markets. Building trust and brand reputation are essential requirements in seafood marketing (Kaufmann 2013). Few large traders dominate in the international wholesale marketing of seafood products. In this business, expanded scales of operation serve as signals of credible reputation (Geirsson and Trondsen 1991; Doeringer and Terkla 1995; Anderson 2003).

Most producers with Chilean seabass fishing operations have longer-term contracts with specific distribution networks at significant export markets (U.S., Japan, and other East Asian countries). Few large wholesalers dominate in each of these markets, investing heavily in brand equity positioning. Getting reliable access to large international wholesale brokers is an important barrier to entry into this industry. Think of firms operating in the Chilean seabass industry as part of a global oligopoly market in which few multinational suppliers compete; and whose fishing operations, at different fishing grounds, are integrated with country-specific distribution networks in other end-consumer markets (Peña-Torres and Fernández 2010).

## Appendix 2. Entry Pressures and Price Spikes

Figure 1 and Table 1 (main text) show that awarding (AP) prices skyrocketed at some auctions. At each of these auctions, entry pressures triggered more intense bidding competition. Table A2.1 reports entry threats that occurred at auctions during the English and Dutch periods. Entry threats include both successful and failed entry attempts. The five auctions with price spikes are grey-shaded in Table A2.1.

During the English phase, the two price spikes coincide with the only English auctions where entry attempts occurred (Figure 1). However, both entry attempts failed. In both cases, a group of incumbents bought all lots on offer. In 1995, four incumbents made turns to buy all (10) lots on offer. In 2001, five incumbents made turns to buy all lots on offer; four of these incumbents had also purchased ITQs in the 1995 auction. As a result, the awarding prices spiked, well above the winning bids observed at the other English auctions (for more details on entry-deterrence during these years, see Peña-Torres and Fernández 2010).

The first (2004) Dutch auction was the first time when a newcomer did in fact enter. On that occasion, the entrant bought 3% of the TAC (out of 9% on offer in total). Awarding (AP) prices increased in this auction but did not spike. The third price spike occurred at the second (2005) Dutch auction. In that year, there was a big jump in the number of potential entrants participating in the auction (see Figure 1). Two entrants bought lots (in total, 3.5% of the TAC; see Table A2.1). The larger number of participants in this auction undoubtedly led to stronger bidding competition.

In the following three auctions (2006-2008), there were again successful entrants. Average awarding (AP) prices in these auctions were higher (though they did not spike) than the average AP price during the English phase. Three aspects stand out from the entry events observed in the 2006-2008 period. First, only one entrant out of five newcomers in total that bought ITQs during the Dutch phase kept operating in this fishery until the end of our sample period. Second, from 2006 on, the single surviving entrant (*Globalpesca*) kept buying lots at each of the following Dutch auctions. Third, most of the lots awarded to newcomers, who later exited this fishery, were eventually acquired by *Globalpesca*. Towards the end of our study period, *Globalpesca* became the largest harvester (46% of the TAC) and exporter (35% of total export value) in this fishery. *Globalpesca*'s transition path to becoming this fishery's new market leader started by initially operating only with ITQ rentals. Later, it combined

both ITQ renting and buying. Once Globalpesca's operations had achieved a market share of about 10% of the TAC in this fishery, it started buying ITQs through public auctions (Table A2.2).<sup>1</sup>

The 2006-2008 period was a transition period in terms of market leadership in this fishery. As Globalpesca's market share steadily increased, Pesca Chile's share (until then, the largest incumbent) did the opposite. The 2009-2010 auctions were part of the consolidation of a new market leader (Globalpesca) in this fishery. In both auctions, the only bidders who acquired ITQs were the two leading firms (Table A2.1). The price spikes observed in these two auctions reflect a 'fighting-for-leadership' rivalry then unfolding between the two most prominent firms in Chile's seabass industry.

Table A2.1 Entry threats at auctions (English and Dutch phases)

Auction for the fishing year:	Potential Entrant	PE/T	Successful Entry?	(% of TAC bought by E) (Total % TAC auctioned)	Other information
1995	<i>Angelini Group</i>	1/9	N	0	At that time, the <i>Angelini Group</i> was the largest economic conglomerate in Chile. It had substantial investments in different Chilean industrial fisheries (but not in the SB business).
2001	<i>Pesquera Albatros</i>	1/9	N	0	It is a small (regional) fishing company with spare fishing capacity but no well-established access to relevant export networks.
2004	(E1) <i>Sta. Isabel</i>	1/5	Y	(3/9)	Small fishing company
	(E2) <i>Empacadora del Pacífico</i>		Y	(0.5/9)	During 2005, it sold its ITQs to <i>Globalpesca</i> . - Small fishing company
2005*	(E3) <i>Océano Atlántico</i>	9/14	Y	(3/9)	- Soon after the auction, this firm's ITQs became void (did not pay 1 <sup>st</sup> installment). <i>P. Chile</i> , <i>Sta. Isabel</i> and <i>Globalpesca</i> were the subsequent buyers of these ITQs.
	<i>Sta. Isabel</i>		Y	(1/19)	- At the end of 2006, this firm sold all its ITQs. <i>Globalpesca</i> bought them all.
2006*	(E4) <i>Globalpesca</i>	3/6	Y	(4/19)	- In 2005, <i>Globalpesca</i> caught 13% of SB landings in Chile while owning 8% of TAC. - <i>Globalpesca</i> started fishing SB by first renting ITQs (since 1999). Later it also

				bought ITQs in the secondary market (since 2003)
2007*	<i>Globalpesca</i>	2/5	Y	(1/10)
	<i>Globalpesca</i>		Y	(1/10)
2008		2/5		Small fishing company. This same year this firm sold all its ITQs to another small company (which soon ended up renting these ITQs).
	<i>(E5) Foodcorp</i>		Y	(1/10)
	<i>Antarctic Sea **</i>		Y	(2/10) Ownership-related to the 2 <sup>nd</sup> largest firm in Chile's SB industry.
2009*		4/6		- In 2009, Globalpesca caught 46% of SB landings in Chile while owning 22% of the TAC.
	<i>Globalpesca</i>		Y	(3.5/10)
	<i>Antarctic Sea **</i>		Y	(3/10)
2010		2/4		- In 2010, it caught 46% of SB landings in Chile, while it owned 42% of the TAC.
	<i>Globalpesca</i>		Y	(3.5/10)

Notes: T= Total number of participants at each auction; PE= Number of Potential Entrants; Ei: Entrant i; Yes: Y; No: N; SB: Chilean seabass; \*: in these years, we only report details about the successful entrants. \*\*: *Antarctic Sea Fisheries S.A.* was a de facto sister company of one of the largest incumbents in this fishery (*Pesca Chile*). We count this firm as a 'potential entrant' only in Table A2.1. It helps us to reveal a 'fighting-for-leadership' rivalry.

Table A2.2. Matrix of Entry Events: Secondary quota market

Fishing Year →	English period										Dutch period																						
	1998		1999		2000		2001		2002		2003		2004			2005			2006			2007			2008			2009			2010		
Entrant ↓	QB	QR	QB	QR	QB	QR	QB	QR	QB	QR	QB	QR	QA	QB	QR	QA	QB	QR	QA	QB	QR	QA	QB	QR	QA	QB	QR	QA	QB	QR	QA		
Globalpesca	1.5		11.8		10.1		5.76		3.6		6**		2		8		0.5	5.7		0.5	8.8	4*	8.5	7.7	1	12.1	1		23.4	3.5	16.5	6.5	3.5
Total Quota holding */ Landings	0		0		0		0		0		6		5.3		12.9		8.2		10		19		19		22.1		42.1		46.1		45.9		
Santa Isabel													3*		0		1**	0	1		-5***												
Total Quota holding */ Landings													3		3		5		3.1														
Empacadora del Pacifico														-0.5***	0.5*	0																	
Landings																																	
Océano Atlántico														0	3*	3	0.5		-3***														
Total Quota holding */ Landings																																	
Foodcorp																																	
Landings																																	
Isla Edén																																	
Total Quota holding */ Landings																																	
Entry and fishing operations only via ITQ renting:																																	
Emdepes SA	0.016	0.02	0.09	0.12	***																												
Total Quota holding */ Landings	0	0.016	0.02	0.09	0.12																												
Calcurrepe			2.4	1.2	2	1.9		1.8		***																							
Total Quota holding */ Landings			0	0	0	0		0		1.9																							

Source: Prepared by the authors based on Subpesca (official) data.

Note: Numbers are expressed as % of the corresponding TAC.

Notation: QB= Quota buying at the secondary market; QR: Quota renting at the secondary market; QA= Quota buying at auction; \*: beginning of (firm-specific) quota buying at auctions; \*\*: beginning of (firm-specific) quota buying at the secondary market; \*\*\*: year of complete exit from this fishery.

### Appendix 3. Industrial Concentration at the Chilean Seabass Fishery

Ever since its beginning, the auctioning process was confronted with a small number of participants in this fishery, either if we measure industrial concentration by market shares in total annual landings or quota ownership (see Figures A3.1-2, this Appendix). During the period studied, the number of ITQ owners declined from eleven (1993-94) to five (2010; see Fig. A3.1), while harvesters fell from nine to three (Fig. A3.2). Similar numbers apply to auction participants (see Table 1). Thus, high industrial concentration implied a nontrivial risk of bidder collusion from the beginning of the auctioning process.

All incumbents belonged to one or the other of two (fishing) trade associations (groups A1 and A2). There is evidence that each association's members repeatedly engaged in different sorts of trading: e.g., mutual trading at the quota resale market or joint operations to combine catch landings and export contracts (Subpesca's ITQ-holding records; IFOP's export records; Isofish 1999). These natural groupings of all incumbents that participated at the ITQ auctions into two trade associations may have been instrumental in facilitating bidding coordination among incumbents. (Source: interviews held with Subpesca's staff)

We have seen that getting access to large international wholesalers is an important barrier to entry into this industry. Exporters play a fundamental role in accessing trading networks. During most of the English period, the largest exporter (group A1's member) controlled 50% or more of the exported tonnage of Chilean seabass products. The second-largest exporter (group A2's member) had market shares that ranged between 19%-28% during the 1997-2003 period. Other exporters' shares were much smaller. High industrial concentration at the export stage can facilitate the enforcement of collusion at auctions. A leading exporter could use its advantageous market position to punish defectors from a coordinated bidding scheme.

By contrast, during most of the Dutch period, the industrial concentration at the export stage steadily declined. From the early 2000s on, there was an increasing entry of new exporters. The HHI index, measured in terms of firms' exported tonnages, monotonically fell from 3200 (the year 1997) to a minimum of 1062 (years 2006-2007), to then show a partial recovery up to a value of 1908 (the year 2010). In parallel, during 2003-2010, most of group A1's firms progressively shifted their Chilean seabass operations out of Chilean waters (Isofish 1999). By 2010, only one of A1's members remained operating in this fishery.

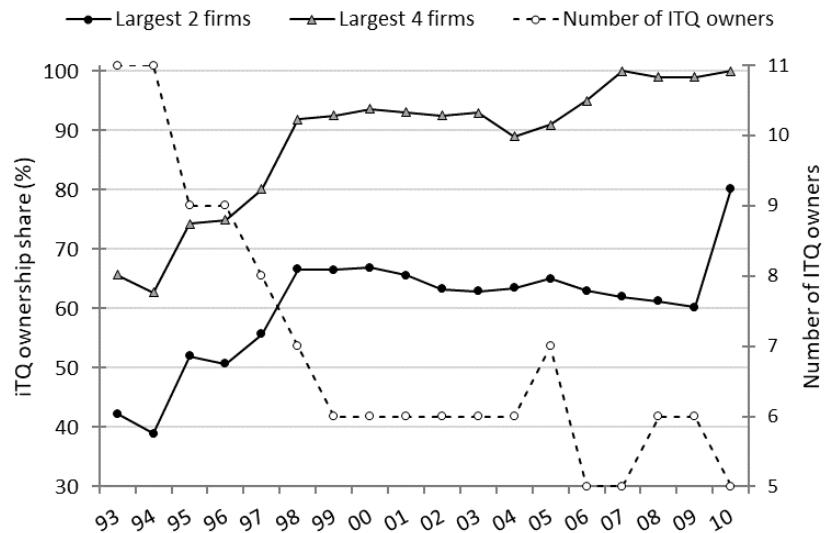


Figure A3.1. Shares (%) in Quota Ownership (% of TAC)

Source: Prepared by the authors based on Subpesca's data.

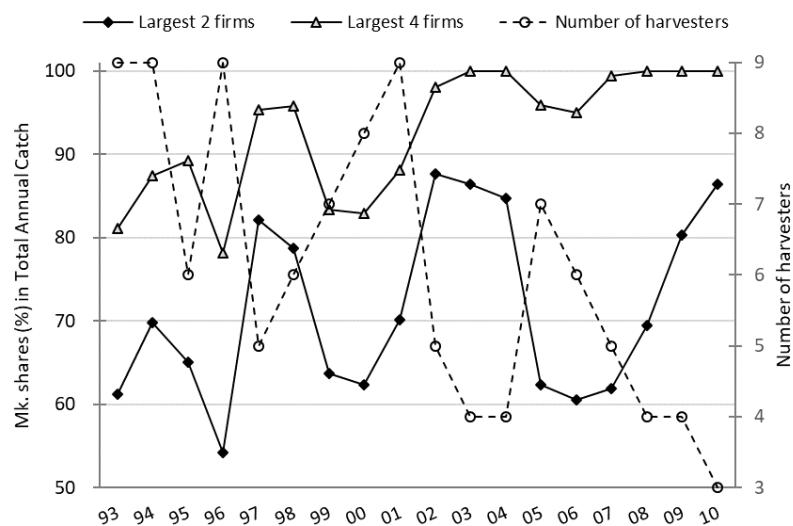


Figure A3.2. Shares (%) in Total Annual Landings

Source: Prepared by the authors based on Subpesca's data.

#### Appendix 4. Revenues in a Reference Auction Model

Here we explain theoretical revenues obtained from a numerically-calibrated model where ( $N > 1$ ) bidders compete in sequential first-price auctions for multiple ( $L > 1$ ) lots (ITQ fishing rights) offered each year. Yearly auctions are assumed to be independent processes. Other assumptions of the reference model are (based on Salant 2014, Ch. 6):

1. Each auctioned object (lot) represents 1% of the TAC. The number  $L$  of auctioned lots is year-specific. The value  $L$  results from considering the TAC's percentage auctioned each year (see Table 1, row 1).
2. The number  $N$  of bidders is also year-specific. It corresponds to the number of participants at each yearly auction (Table 1, row 9).
3. At the beginning of each year, each bidder  $j$ 's demand function for objects  $i$  on sale ( $i=1,\dots,l_j$ ) is drawn from a uniform distribution in the  $[0, 1]$  interval, where  $l_j \geq 1$  denotes bidder  $j$ 's number of demanded objects (per year). Let  $V_j^i$  denote bidder  $j$ 's demand function, which specifies per-object ( $i=1,\dots,l_j$ ) valuations. Within a given auction, the valuations ( $V_j^i$ ) remain fixed throughout the sequence of auctioned objects. When making bids, bidders know their (own) valuation and all previous bids.
4. The valuations ( $V_j^i$ ) are private information. However, any bidder can perfectly predict the total number of objects demanded (based on the observed number of bidders). Based on the Chilean seabass fishery's stylized facts, let us assume the two largest bidders each demand  $l_j=4$  objects per (yearly) auction. Regarding the remaining bidders, each demands  $X$  objects ( $l_j=X$ ) per year, where  $X$  is subject to sensitivity analysis in our empirical calibration of the analytical solution to the model. Figure 3 (in the main text) reports the resulting revenues for  $X=(1.5; 2; 2.5)$ . At a given annual auction, each bidder  $j$  can get, at most, the total number  $l_j$  of objects it demands, but the exact number of objects it is awarded depends on whether its valuations ( $V_j^i$ ) are higher or lower than the (per-year uniform) equilibrium price of the auctioned objects.<sup>2</sup>
5. Bidders are risk-neutral and have no budget constraints.
6. Given this set of assumptions, each bidder can estimate the expected value for the ( $L+1$ )-ordered (bidders') valuations  $V_j^i$ , among all bidders' valuations per year ( $M$  valuations in total,  $M = \sum_{j=1}^N l_j$ ) once all  $M$  valuations are ranked from the highest to the lowest value. In our simulation results, we assume  $M > L$ . The expected value

for the  $(L+1)$ -ordered valuation ( $V_j^i$ ) will be the expected awarding price for the last ( $L$ )-auctioned object at a given (yearly) auction. This result is because the competition for the last-auctioned lot behaves like a static first-price auction: its awarding price will correspond to the second-highest valuation for the last auctioned object, i.e., the expected value for the  $(L+1)$ -ordered valuation (Krishna 2010; Salant 2014).

Solving by backward-induction and assuming fully competitive arbitrage between the different objects auctioned each year, the expected (per-object) equilibrium price (denoted by  $P$ ) will be the same within a given year for all  $L$  objects auctioned that year (Salant 2014, Ch. 6). The equilibrium winning bid will be a uniform price ( $P$ ) within a given yearly auction. Mathematically:

$$P = \frac{(N^a - L)}{(N^a + 1)} \quad (\text{A4.1})$$

$N^a$  is the adjusted number of bidders participating in a yearly auction, with  $L$  (identical) objects on offer. The number  $N^a$  of bidders transforms the original number  $N$  of (multi-object demand) bidders into single-object demand bidders. Hence,  $N^a=M$ . Thus, in our simulations:

$$M = N^a = [2 \cdot 4 + (N - 2) \cdot X] \quad (\text{A4.2})$$

$X$  is the (simulated) number of objects that each bidder demands per yearly auction (except the largest two bidders at each auction; we assume each of these two bidders demands four lots per year).

To transform the theoretical equilibrium price  $P$  into the scale of the observed awarding prices, we calculated an empirical valuation support equal to  $[V_{min}, V_{max}]$ , with  $V_{min}$  and  $V_{max}$  corresponding to the actual (implicit) minimum and maximum valuations per 1% of the TAC. We proxy these limit valuations by the observed minimum and maximum (yearly-average) awarding prices during our study period. We use the following formula to transform valuations in the  $[V_{min}, V_{max}]$  support into valuations in the range  $[0,1]$ :

$$x_i = \frac{V_i - V_{min}}{V_{max} - V_{min}} \quad (\text{A4.3})$$

Using A4.3, we rescale the theoretical (per-year) equilibrium price  $P$ , initially expressed in the  $[0,1]$  realm, into a price based on valuations  $V_i$  in the  $[V_{min}, V_{max}]$  realm. The theoretical revenue per year is obtained by multiplying

the yearly equilibrium price by the number of objects auctioned each year. These revenues are then compared with the collected (actual) revenues.

We excluded the 1993 and 2006 auctions from our calibration exercise. We did so for two reasons. First, the percentage of the TAC auctioned in each of these two auctions was substantially higher than in other years of our sample (90% and 19% of the TAC, respectively). In both years, the ratio (Number of 1%-homogeneous auctioned objects/Number of bidders) was substantially higher than in other years. This feature led to outlier (unreasonable) results for the theoretical revenues (in both years).<sup>3</sup> Second, a substantial fraction (90%) of the TAC was (initially) allocated in the first auction. Hence, it seems reasonable to presume that incumbent collusion in that first auction was very unlikely (this conjecture was confirmed in interviews with Subpesca's staff).

### Appendix 5. Autocorrelation tests

To test for autocorrelation, we computed a Durbin test. This test assumes a time-series structure. For this purpose, we aggregated our data computing per-auction averages. We then calculated the test using 18 yearly average observations. Because dummies F and E have different values within an auction, their averages are continuous variables between 0 and 1. Thus, we computed the test for two variants: (i) using dummies rounded to the closest integer, and (ii) using continuous values. The model tested uses OLS and robust standard errors. We fail to reject the null ( $H_0$ : no autocorrelation) for all models and variants (Table A5.1).<sup>4</sup> We conclude from this set of results that autocorrelation is not a relevant issue in our estimation strategy.

Table A5.1. Autocorrelation tests for preferred models ( $H_0$ : No autocorrelation)

	M1	M2	M3	M4	M5	M6
Durbin's test (rounded values)						
F statistics	0.026	0.181	0.183	0.087	0.067	0.553
( <i>p</i> -value)	(0.879)	(0.712)	(0.710)	(0.780)	(0.819)	(0.535)
Durbin's test (continuous values)						
F statistics	0.026	0.188	0.026	0.087	0.085	0.087
( <i>p</i> -value)	(0.879)	(0.694)	(0.879)	(0.780)	(0.790)	(0.779)

### Appendix 6: Proof of result in equation (5), main text

**Initial situation** (with  $n$  symmetric followers):

The leader (denoted by  $L$ ) produces  $q_L$

All firms are equal with total cost equals to  $C(q) = cq$ . (There are no fixed costs)

Inverse Demand:  $P(Q) = (a - bQ)$

#### Stage 2:

The representative follower (denoted by  $i$ , with  $i=1,\dots,n$ ) solves:

$$\max_{q_i \geq 0} \left[ \left( p \left( q_L + \sum_{j=1}^n q_j \right) - c \right) q_i \right] = \left[ a - bq_L - b \sum_{j=1}^n q_j - c \right] q_i$$

In equilibrium:

$$q_i^*(q_L) = \frac{1}{b} \left[ \frac{a - bq_L - c}{n+1} \right] \quad i = 1 \dots n$$

**Stage 1:** (Given the Stackelberg leader's first-mover advantage)

The leader solves:

$$\begin{aligned} \max_{q_L \geq 0} \left[ \left( a - bq_L - \frac{n(a - bq_L - c)}{n+1} - c \right) q_L \right] &= \frac{1}{n+1} \max_{q_L \geq 0} [(a - bq_L - c)q_L] \\ q_L^* &= \frac{a - c}{2b} \end{aligned}$$

Thus, the optimal quantity supply for the representative follower is:

$$q_i^*(q_L^*) = \frac{a - c}{2b(n+1)} \quad i = 1 \dots n$$

Then, in equilibrium:

$$P^* = a - \frac{a - c}{2} - \frac{n(a - c)}{2(n+1)} = \frac{2(n+1)a - (n+1)(a - c) - n(a - c)}{2(n+1)} = \frac{a + (2n+1)c}{2(n+1)}$$

Therefore, profits are:

$$\pi_i^* = \left[ \frac{a + (2n+1)c}{2(n+1)} - c \right] \frac{(a - c)}{2b(n+1)} , \quad i = 1 \dots n$$

$$\pi_i^* = b \left[ \frac{a - c}{2b(n + 1)} \right]^2 = bq_i^{*2} , \quad i = 1 \dots n$$

$$\pi_L^* = \left[ \frac{a + (2n + 1)c}{2(n + 1)} - c \right] \frac{(a - c)}{2b}$$

$$\pi_L^* = \frac{(a - c)^2}{4b(n + 1)}$$

**Final situation** (with  $n+1$  symmetric followers):

Here we have the same leader but now facing  $(n+1)$  symmetric followers. The profits of the representative follower  $i$  and the leader  $L$  are:

$$\pi_i^* = b \left[ \frac{a - c}{2b(n + 2)} \right]^2 \quad i = (1, \dots, n + 1)$$

$$\pi_L^* = \frac{(a - c)^2}{4b(n + 2)}$$

Then:

$$\frac{\Delta\pi_L}{\pi_L^0} = \frac{\pi_L^0 - \pi_L^1}{\pi_L^0} = \frac{\frac{(a - c)^2}{4b(n + 1)} - \frac{(a - c)^2}{4b(n + 2)}}{\frac{(a - c)^2}{4b(n + 1)}}$$

$$\frac{\Delta\pi_L}{\pi_L^0} = \frac{\frac{1}{(n + 1)} - \frac{1}{(n + 2)}}{\frac{1}{(n + 1)}}$$

$$\frac{\Delta\pi_L}{\pi_L^0} = 1 - \frac{\frac{1}{(n + 2)}}{\frac{1}{(n + 1)}}$$

$$\frac{\Delta\pi_L}{\pi_L^0} = 1 - \frac{n + 1}{(n + 2)} = \frac{(n + 2) - (n + 1)}{(n + 2)}$$

$$\frac{\Delta\pi_L}{\pi_L^0} = \frac{(n + 2) - (n + 1)}{(n + 2)}$$

$$\frac{\Delta\pi_L}{\pi_L^0} = \frac{1}{(n + 2)}$$

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<sup>1</sup> Globalpesca was a technological pioneer in this fishery. It was the first company to use a new fishing net that increased catch yields in this fishery. This innovation reduced sperm whales' and orcas' predation on Chilean seabass (for a similar story, see *The Economist* October 26, 2017).

<sup>2</sup> In this modeling exercise, we assume uniform price auctions. Nonetheless, in reality, per-lot awarding prices could vary within a given yearly auction.

<sup>3</sup> In both (exceptional) yearly auctions, the number ( $N^a - T$ ) was negative. This feature contradicts our modeling assumption of  $M = N^a > T$ . As a result, the predicted (theoretical) equilibrium price ( $P$ ) was negative in both years.

<sup>4</sup> Looking for robustness, we also computed the Wooldridge test for serial correlation. This test is designed to check for autocorrelation in a panel-data structure. This test can be conducted using an unbalanced panel with gaps (Drukker 2003), assuming the panel unit's identifier is the per-lot selling order and the time variable is the auction year. The estimation uses robust standard errors (clustered at the order variable level). The results imply that we fail to reject the null ( $H_0$ : no autocorrelation) at 94% of confidence. Results are available upon request.