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RESEARCH ARTICLE

Fishing vessel efficiency, skipper skills and hake price transmission in a small island economy

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Abstract Determinants of vessel efficiency and vertical/horizontal price transmissions in consumer markets are key elements for assessing the viability of a fishery, particularly for a small fishery-dependent economy. An open issue also concerns whether vessel efficiency levels influence export prices. The paper sets off with a review of evidence from other countries, followed by hypotheses for the Falkland Islands. To test these hypotheses, the analysis first applies a stochastic frontier model accounting for latent skipper skills, to a monthly 2008–2016 panel of fishing vessels operating in the Islands. Using estimated vessel inefficiency by licence type as a proxy indicator of product quality and extra costs of transhipment, the study moves on to examine price adjustments of Falkland hake and other finfish sold at Spanish ports vis-à-vis two major south Atlantic hake supplier countries—Argentina and Namibia—and local traders. Lastly, based on full sample and rolling widow regressions on 2004–2016 monthly data, the analysis formulates and estimates threshold autoregressive models for the hake value chain in Spain, as the largest European port-of-entry and market for fresh and frozen hake, including from the Falklands. Once different output frontiers are accounted for, vessels with licences for hake as their main target do not outperform, in terms of technical efficiency, less-valued finfish vessels. Besides evidence of increasing integration within supplier and consumer markets, econometric results suggest some degree of price 'leadership' by Namibian hake exporters and asymmetric behaviour in short-run price adjustments by Spanish retailers. However, producer and consumer markets turn out to be weakly interlinked.

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Introduction

Development strategies in remote and small economies typically face chronic problems, including high vulnerability to world market prices, reliance on few export commodities and high transport, freight and fuel costs. In the Falklands, unsolved political issues and slowdowns in oil and gas developments after the 2010–2012 exploration boost further complicate the situation, with plans being put on hold following oil price drops in 2014–2015. Fisheries represent by far the most relevant source of local government revenues. In 2011, world market shares for *Loligo* squid and toothfish from the Falkland Islands amounted to nearly 13 and 8%, respectively. This is a substantial achievement, in view of the size of the Islands' economy, with a small number of economic activities (besides fishing and hydrocarbons, mainly sheep farming and tourism) and a population of less than 3000 residents excluding military personnel (Policy Unit (PU) 2015). As for fishing activities other than *Loligo*, finfish catches, particularly of southern hake and rockcod, have had a relevant role in fish exports and are regarded to have a scope for further expansion also in view of climate changes.

Based on climate change simulations of marine ecosystem-based models, by 2030, the productivity of capture fish production from some seas around high-latitude regions (Greenland, Iceland) and/or at the confluence of cold and warm oceanic streams (Falklands) will increase by 9%, relative to baseline scenario projections (World Bank 2013). Besides supply side determinants, fish price dynamics is likely to benefit from increasing demand, fostered by economic and demographic changes such as urbanisation, particularly in Asia (Kobayashi et al. 2015). However, except for *Illex* squid (Appendix 1), fish exports from the Falklands almost exclusively target Spanish ports. Spain is the largest importer of fish and fishery products in Europe, and the fourth largest in the world, behind the USA, Japan and China. Moreover, it is the main European consumer market and port-of-entry for—fresh and frozen—hake and seafood as a whole (Fraser 2015; Nielsen et al. 2009). Seasonality and economic shocks can affect the magnitude and levels of substitutability among fishery products, such as demand shifts from high- to lower-value species. Demand- and supply-related factors are especially relevant for fish sales such as hake, given their role in signalling price changes for other species (Johnston 2007; Floros and Failler 2004).

An analysis of the above factors can help better understand developments and viability of a fishery and the possible impact of changing fishing efficiency on export price determination for a small open economy. In the Falkland Islands, in 2005, a new legislation was laid out (effective since 2009–2010), with allocations of individual transferable quotas (ITQs) over an initial 25-year period—until 2031. Regulations on transferable rights concern total allowable catch (TAC, for toothfish) and total allowable effort (TAE, for finfish and squid species, except for jig-caught *Illex*—exempted so far due to wide shifts in annual stock levels, although consultations are currently underway). The new regime has striven to promote greater competitiveness, efficiency and diversification in the sector. A relevant policy issue for the Falklands—and indirectly for other fishery-dependent economies with small domestic markets—is to assess to what extent this enhanced regulatory environment for fishery sustainability has improved fishing efficiency across the vessels and companies involved. Moreover, a related question concerns whether the thus envisaged increased efficiency, by allowing better focus on fish quality and standards (as argued in support of ITQs: Sanchirico and Newell 2003), has influenced the price performance of Falkland fish exports. A major objective of the new regime is to strengthen the capacity of local fishing companies and their ability to benefit from vertically integrated operations of joint-venture associates, with a progressive development of more value-added activities, including processing, transhipment and marketing (Harte and Barton 2007).

This analysis is a first study of its kind for the Falkland Islands, and for the reasons explained above, it focuses on finfish fisheries, especially hake and rockcod. The study starts by estimating inefficiencies of finfish fishing vessels operating in the Islands, based on 2008–2016 panel data of southern hake catches. Subsequently, along with prices and sales of other Falkland finfish and major South Atlantic hake suppliers, average vessel technical inefficiency estimates serve as a partial proxy of 'residual' factors in regressions of hake prices for Falkland finfish sold at Spanish ports. Relative to demand-side factors, the last part—and third aim—of the analysis examines the hake value chain in the Spanish market. Even though these issues are analysed often separately, greater flexibility and efficiency in the production process can pave the way to improved storage, distribution and marketing of fish products, particularly in the presence of increasingly integrated global markets and more diversified value chains (Felix 2012; van Anrooy 2003).

The remainder of the paper develops as follows. Section 2 highlights evidence on finfish and similar product markets in other countries, relative to *vertical*, *horizontal* and *indirect* price transmission and puts forward hypotheses for the Falklands.[1] Section 3 introduces a stochastic production frontier model accounting for fishing skipper skills and its interactions with input use, followed by an operational framework for testing long-run equilibrium in main import and consumer markets (from the viewpoint of a small fishery-dependent economy) and threshold autoregressive (TAR) models geared to test for asymmetric price transmission (APT). Section 4 presents and discusses data and econometric estimates for the goals of the study, and Sect. 5 draws concluding remarks.

Empirical evidence and hypotheses

Price transmission chains

Within a given level of value chain, a number of factors may induce asymmetric price fluctuations, in terms of different magnitude and/or speed of upward versus downward

[1] Despite being often analysed separately, these are intertwined issues in domestic and international markets (Areté 2012). Indirect transmission refers to markets with related—substitutes or complements—products. A price market is leading if its 'supply and demand shocks feed through to other markets' within a system, while remaining largely unresponsive to price changes in these markets (Asche et al. 2007a).

adjustments. Theoretical and empirical work on the subject often points to features of non-competitive markets as the main explanation, such as undercutting or oligopolistic price games to gain market shares, with sharp increases followed by shallow long declines even in the absence of supply and demand shocks. In fisheries as in other primary industries, sub-sectors are often more concentrated downstream than upstream, with producers often reaping relatively smaller benefit from final product values than what would probably otherwise be (Polanco and Bjørndal 2015; Enviro-Fish Africa (EFA) 2006). Although upstream—shipping or *ex-vessel*—prices, which partly reflect supply shocks, tend to lead retail prices down the value chain, some market power often operates in the opposite direction or acts both ways with reciprocal influences in price transmission.

However, price signal distortions, and some degree of price leadership, can also characterise markets with relatively homogeneous products and many small firms—including many fisheries—where market power is unlikely (Asche et al. 2007b). Examples include companies willing to dampen price shock effects during low demand periods (e.g., with increased inventories), or able to delay or anticipate price adjustments due to higher profit margins and economies of size in information gathering, respectively. Due to adjustment and labelling costs, which characterise many agro-food industries, downward price transmission from producer or wholesale to consumer markets is often more incomplete and with delayed pass-through than the respective price peaks. Similarly, because of floor price support policies, wholesalers can expect changes in producer prices to have effects that are more permanent in upswings than downswings (Meyer and von Cramon-Taubadel 2004; Goodwin and Holt 1999).

The intensity of the asymmetric behaviour may also vary depending on strength of long-term contractual agreements within the value chain or the extent of contraction in marketing margins. As long as these margins do not fall below a certain threshold, retailers may keep a consistent behaviour in price transmission to consumers. If this threshold is crossed, retailers may be more reluctant to transmit fish price decreases (Simioni et al. 2013). On the other hand, when storage costs are high for perishable products with short shelf lives, producers can leverage on retailers relative to price cut decisions (Rajcaniova and Pokrivcak 2013). This may apply to the commercial fishing industry, given uncertainty affecting supply conditions and high spoilage costs. Unlike the first case outlined above—Edgeworth price cycles—APT will then imply relatively quicker adjustments to downward price pressures, and vice versa relative slower adjustments upwards, thus reflecting kinked demand curve equilibrium. Hence, no clear scope a priori allows one to predict if APT will be positive or 'negative', that is relatively more favourable to retailers or consumers (Noel 2011; Meyer and von Cramon-Taubadel 2004; Maskin and Tirole 1988).

Finfish supply and demand factors

The hypothesis that processing plant managers influence *ex-vessel* price determination seems to be often not suited to domestic consumer markets of finfish. In Spain, the market chain for fresh hake appears to follow opposite cyclical patterns, with first-hand sale prices more driven by supply factors, wholesale and especially retail sales prices by market segment behaviour (Amigo-Dobaño and Garza-Gil 2011). Relative to Chilean hake, in the long run, ex-vessel prices are highly influenced by changes in international frozen hake export prices and metropolitan domestic fresh hake consumption prices, while remaining largely unaffected by exchange rate changes (even if FOB prices are quoted in foreign currency). Short-run price adjustments largely trace world market conditions (Quezada and Dresdner 2014).

In some countries, prices of newly competing finfish imports appear to lead the evolution of the market and partly displace traditional species, such as *Pangasius* versus hake and cod in the EU (Polanco et al. 2011). Similarly, the expansion in global supply of lower-valued farmed fish can influence short-run price movements of the respective domestic wild fish species catches (relative to French seabass, see Regnier and Bayramoglu 2016). Overall, these results suggest that non-market mechanisms of ex-vessel price determination can be ineffective in the long term, regardless of kinds of price adjustments along market chains. In economies with insignificant domestic demand relative to foreign fish markets—such as the Falklands and, to lesser extent, Namibia—the arbitrage process can also suffer from limited scope for supply shifts of fish landings between domestic and international buyers. This makes local suppliers more vulnerable to international price fluctuations.

Hypotheses for Falkland fisheries

The market share of south Atlantic hake dominates the EU hake market, mainly given by Cape hake (*Merluccius capensis/paradoxus*) from Namibia and southern hake from Argentina. Frozen hake fillet from these countries account for nearly 80% of Spanish import volumes of this item, and almost 60% of domestic frozen hake consumption (Polanco et al. 2016). In both countries, the market is largely characterised by joint ventures of Spanish companies with local suppliers. Before the prolonged recession of the late 2000s in Spain and other markets, Argentina used to have the world's fastest growth fishery, with 90% of fish harvest exported and very high export rates from Patagonian harbours. Subject to conditions in other fishing grounds, Argentine hake catches have tended to highly influence international hake price trends (Lart and Green 2013; UNEP 2002). An ITQ system for four species, including southern hake, has been operating since 2010, with 15-year validity. Fishing licences are reserved for local citizens and companies registered in the country, and concentration limits are set to prevent excessive catch share consolidation (Young 2013). Argentina is the second largest exporter of fish and seafood to Spain—after Morocco—accounting for nearly 7% of the local market (Fraser 2015). However, by far the largest Spanish imports of frozen hake fillets originate from Namibia.

Until January 2016, when it ceased being Generalised System of Preferences (GSP) beneficiary, Namibia maintained market price advantages, over its competitors, of 4–11% for hake products in the EU, due to preferential treatment for exports. The Namibian shares in EU fish markets have tended to range between 30 and 70%, with high values especially for frozen hake. The 'Namibianisation' policy of the labour force is regarded to have possibly reduced the market share of oligopolistic firms, although it may have also hindered achievement and maintenance of scale efficiency in the fishing fleet (Kirchner and Leiman 2014; Enviro-Fish Africa (EFA) 2006). The nearly 18% quota reduction implemented in the Namibian hake fishery was partly responsible for the hake price hike registered in EU markets in 2013. Moreover, Namibian *Merluccius capensis* has a quality premium over other hake species—while remaining at a discount relative to European fresh hake—besides having a shorter transport route to Europe compared with Argentine and Falklands suppliers (Polanco et al. 2016; Lloris et al. 2005). However, hake fish stocks in Namibian waters are likely to remain below sustainable levels, even if improvements in fishery monitoring have discouraged catch underreporting (Ramsden 2013).[2]

Hypotheses on Falkland finfish fisheries focused here relate to the effects of the new fishery regime in terms of vessel efficiency across different finfish licence holders, and the performance of frozen hake shipments from the Islands sold at Spanish harbours. Concerning vessel efficiency, a stochastic production frontier represents a locus of *best practice*, which in a suitably regulated fishery should be able to yield a resource rent, with sustainable economic returns to the 'owner' of the resource. As such, any substantial backlog in vessel efficiency (Table 1, list of variables: *U[LV2(i)]*) is likely to reflect bottlenecks in vessel type, skills of crew, fish targeting ability etc., which can impinge upon product quality and export price performance of the fishery as a whole (Latruffe 2010; Oliveira et al. 2010; Coglan and Pascoe 1999). Relative to the Spanish hake market, product quality, partly associated with origin of the fish, is a key attribute found to influence the price (Asche and Guillen 2012). In this regard, the fishery regime adopted in the Falklands has sought to ensure active involvement in seafood business by ITQ holders and their joint-venture partners.

Relative to performance of southern hake shipments and sales, besides technical efficiency by Falkland fishing vessels, interrelated issues include (i) sales of other Falkland finfish at Spanish ports, (ii) Argentine and Namibian frozen hake exports to Spain and (iii) the value chain of the hake market in Spain. Given relatively small market shares of Falkland finfish, cross-price elasticities of finfish sales can be low even in the presence of close substitutes. Hence, one can first check whether Falkland hake prices have been unresponsive to price movements of other finfish exports from the Islands, in the short-to-medium run. An additional relevant question is to assess changes in price 'leadership' of main south Atlantic hake suppliers, and their effects for the Falklands over time and across seasonal variations. Lastly, even if not directly related to sales prices of Falkland finfish, understanding long- and short-term relationships between different stages of the fresh hake market chain in Spain can shed further light on development prospects of the fishery in its main consumer market.

Fishing vessel efficiency and market responses

Finfish production frontiers

Across fishing vessels, one can distinguish between *technical* and *allocative* inefficiency (Greenville et al. 2006). The former is measured in terms of relative distances from a 'best practice' production frontier, which traces the maximum amount of output

[2] Similar to the Falkland/Malvinas Current in the Patagonian Shelf ecosystem, the Benguela Current marine ecosystem makes fishing grounds off the Namibian coast one of the most productive in the world. Fishing rights, granted over periods between 7 and 20 years (depending on levels of investment and Namibian ownership), are not freely transferable. Namibia has forfeited part of the potential rents from fisheries for the sake of job creation, fish processing, and local ownership. In recent years, due to benefits from onshore processing, fishing right allocations have gradually shifted from licenced freezer trawlers to wet fish vessels, with rebates on fishing fees for the above objectives, thus opting for a more state-controlled system of fishery management. However, in practice, lack of finance and processing facilities has implied sales of new company shares and leasing of quotas to large operators (Benkenstein 2014).

Table 1 Descriptive statistics (Falkland finfish trawlers; Spanish imports of frozen finfish)

Falkland finfish trawlers (1/2008-7/2016)								
Variable (original data)	*hake* [2202]	*rockcod* [2268]	*illex* [752]	*crew* [2290]	*effort* [2290]	*grt* [2290]	*bhp* [2290]	*length* [2290]
mean	48.6	156.6	38.7	29.2	327.3	1240.1	1971.3	61.1
minimum	0.02	0.04	0.01	21	4.2	696	1275	42.7
maximum	802.8	1144.4	814.5	80	1375.6	3201	4000	95.6
Variable (natural logs)	*Hake*	*Rockcod*	*Illex*	*Crew*	*Effort*	*GRT*	*BHP*	*Length*
mean	2.74	3.91	1.4	3.36	5.42	7.08	7.56	4.1
standard dev.	1.83	1.94	2.47	0.17	0.997	0.31	0.21	0.14
minimum	-3.91	-3.22	-4.61	3.04	1.44	6.54	7.15	3.76
maximum	6.69	7.04	6.7	4.38	7.23	8.07	8.29	4.56
skewness	-0.75	-0.85	-0.03	1.85	-0.88	0.9	0.28	-0.09
kurtosis (μ_4)	3.51	3.33	2.14	11.47	3.36	2.36	3.25	2.69
South Atlantic frozen finfish imports (Spain)								
Variable	*Hake price*	*Hake price Arg.*	*Hake price Nam.*	*Other finfish pr.*	*Hake sale*	*Hake sale Arg.*	*Hake sale Nam.*	*Other finfish sale*
σ/μ (4/04-12/12)	0.21	0.15	0.14	0.24	0.92	0.5	0.65	0.85
σ/μ (1/08-4/16)	0.16	0.16	0.11	0.47	0.92	0.55	0.52	0.79

In brackets: number of observations. Mesokurtosis (Gaussian distribution): $\mu_4 = 3$. Coefficient of variation (σ/μ): original data

List of variables

Falkland finfish fisheries (natural logarithms, except for trend variable; January 2008-July 2016)

Hake	southern hake catch (tonnes)
Rockcod	rockcod catch (tonnes, *Patagonotothen ramsayi*)
Illex	*Illex* squid catch (tonnes, *Illex argentinus*)

Crew	number of crew
Effort	number of hours spent at sea for fishing (fishing effort)
GRT	vessel gross registered tonnage
BHP	BHP (brake horsepower)
Length	vessel length (metres)
Trend	intra-annual trend by month (1-12, within each year)
Dummy variables	
ITQ	years with new operating ITQ access regime for finfish vessels (1 2010-16; 0 2008-09)
Island S. Georgia	vessel upgrades partly induced by more stringent access regime in South Georgia Island seawaters (1 2014-16; 0 2008-13)
Licence F	F licence (skate)
Licence G	G licence (restricted finfish and *illex* squid)
Licence WZ	W-Z licence (restricted finfish)
Illexfs	*Illex* squid fishing season (1 March-April-May; 0 other months)
South Atlantic frozen finfish and Spanish market chain (all variables in natural logarithms; prices in euro/kg and quantities in tonnes; April 2004-April 2016)	
Hake price	Spanish import price of Falkland Islands frozen hake
Hake price Arg.	Spanish import price of Argentine frozen hake
Hake price Nam.	Spanish import price of Namibian frozen hake
Hake sale	frozen hake import from the Falklands (Spanish ports)
Hake sale Arg.	frozen hake import from Argentina (Spanish ports)
Hake sale Nam.	frozen hake import from Namibia (Spanish ports)
Other finfish price	Spanish import price of Falkland frozen finfish other than hake
Other finfish sale	import of Falkland frozen finfish other than hake (blue whiting, skates and others not separately classified; Spanish ports)
Harbour price	harbour (producer) price of fresh hake (average in 15 major Spanish ports)
Retail price	retail price of fresh hake (weighted average in Spanish provincial administrative centres)
Wholesale price	wholesale price of fresh hake (per net drained weight, without VAT; Spanish wholesale market network)

U[LV2]	mean inefficiency of Falkland finfish vessels (log-transformed monthly average value of inefficiency scores from model LVRP SF[2])
U[LV2(i)]	mean inefficiency of Falkland finfish vessels, by licence type (vessel operating with: $i=a$ A-Y ['finfish']; $i=n$ F, G, or W-Z; $i=\mu$ mean of *(a)* and *(n)* values)
Dummy variables	
Post1	excluding two main downswings in Falkland hake prices (1 all months except March and October)
Post2	excluding main intra-year downswing in Falkland hake prices (1 all months except March)
Prior	excluding end-of-year seasonal upswing in Spanish retail prices of hake (1 all months except December)

produced with a given technology and set of inputs. Conversely, for a given output, technical inefficiency arises from utilisation of inputs in excessive amounts. If the focus is on revenues, costs or net returns, allocative inefficiency stems from suboptimal proportions of inputs vis-à-vis their relative prices. Relative to Falkland finfish fisheries, limited scope for vessel replacements makes allocative efficiency a relatively longer-term goal compared with technical efficiency (TE). A third source of inefficiency is *scale* inefficiency, namely production at a non-optimal size of operation, due to scale economies or diseconomies. For instance, a fishing company may be efficient in technical and allocative terms but operating at non-optimal scale. Under constant returns to scale, TE reflects optimal performance in input organisation, such as to ensure that no equally proportionate reduction of inputs still allows production of a given output. In the absence of scale inefficiency, input-oriented (proportional reduction in input usage, with output held constant) and output-oriented (proportional increase in output, with inputs held fixed) measures of TE yield equivalent results (Coelli et al. 2005, p. 180; Grafton et al. 2000; Farrell 1957, p. 259).

As from early contributions (Farrell 1957), TE is measured in terms of output effects of equally proportional changes of inputs, and is associated with the role of managerial effort in terms of quantity and quality of production.[3] This poses specific challenges for stochastic frontier models, since managerial effort depends largely on unobservable factors, thus potentially inducing bias in parameter estimates and inflated inefficiency estimates in standard stochastic production frontier equations. Particularly in the fishing sector, management (skipper skill or 'skilled captain' hypothesis) is a key element for successful catches, even if the relative contribution of skipper skill and luck can vary depending on time frequency. Over aggregate, i.e. annual or monthly as opposed to daily, data, luck tends to level out and management appears to assume a greater role (Alvarez and Arias 2014; Alvarez and Schmidt 2006).

To avoid management bias in parameter estimates, some studies use ad hoc dummies and categorical variables in production equations. For fisheries, these variables typically concern attributes of the skipper and their interactions with the vessel, such as fishing experience, level of formal and vocational training, and place of origin or ethnicity (Tingley et al. 2005; Viswanathan et al. 2001). This procedure can face pitfalls, since measurable attributes inaccurately capture skipper abilities. Moreover, if not suitably chosen, some attributes can be misleading indicators of managerial experience. For instance, the age of a fishing company has limited interpretability if ownership changes take place without substantial changes in management (Page 1980, p. 333).

As an alternative approach, Alvarez et al. (2005) formulate a model with latent variable-random parameters stochastic frontier (LVRP SF), which incorporates managerial ability as a fixed input, captured by a largely unobservable latent variable (m_i) and its interactions with input(s) within a transcendental logarithmic (*translog*) specification. As a second-order approximation with Taylor series expansion of theoretically

[3] In an alternative definition of TE (Koopmans 1951), input and output 'slacks' in production imply no proportionate input changes. However, the problem of slacks can be spuriously due to data arrangement, and largely overlaps with allocative efficiency (Coelli et al. 2005). More broadly, as for possible links with *allocative* inefficiency, in the absence of input market distortions, technically inefficient managers are likely to be less aware of alternative production techniques and opportunity costs. Relative to *technical* versus *scale* efficiency, one should note that 'economics concepts such as returns to scale etc., have no unambiguous meaning until the efficiency frontier is attained' (Banker et al. 1984, p. 1080).

suitable functions, this specification allows for varying returns to scale and non-constant elasticity of factor substitution, including the effects of interactions of fishing effort with quasi-fixed inputs. For Falkland finfish fisheries, the latter include vessel crew and gross registered tonnage. Apart from the truncation 'error', the *translog* is regarded as especially suited to fishery analysis (García del Hoyo et al. 2005; Hoff 2002). However, hitherto applications of this model have rather focused on agriculture (Čechura et al. 2015; Wang and Hockmann 2012).[4]

Relative to Falkland finfish, let catches depend on K inputs $x_{it,k}$, e.g. $K = 3$ for crew size, gross registered tonnage and fishing days. Denote optimum (*frontier*) management and actual management as m_i^* and m_i (for vessel i, with $i = 1, .., N$), respectively, with input levels uncorrelated with deviations from optimal management ($E[(m_i^* - m_i)x_{it}] = 0$). In Falkland fishing grounds, whereas the licence for unrestricted 'finfish', i.e. the A-Y type, allows targeting hake, holders of other licence types can only fish hake as by-catch (dummy variables for these licences are listed under Table 1, with A-Y being the implicit category in the analysis). Regardless of licence type, rockcod represents a lower-valued finfish, with its catches regarded to reflect resource availability as a whole: its predators, including hake, tend to migrate into finfish-abundant grounds. Hence, relative to the Falklands, rockcod catches are likely to reflect to some extent finfish catchability and stock. Other control variables include an intra-annual trend t (by month), *Illex* fishing season (*Illexfs*), dummies accounting for fishery regime changes (such as *ITQ*), and different fishing licence types (e.g., *Lic* in a regime with two licence types; on the *Illex* squid and oceanographic/fish migratory features underlying the rationale for using an intra-annual trend, see Appendix 1).

Denote α_i and β_{ki} as random parameters, β_{kg}, β_4, δ_t, δ_{ifs}, δ_{itq} and δ_{lic} as 'non-random' parameters, and N^+ the half-normal distribution of the inefficiency term (u_{it}, with $TE = e^{-u}$). An LVRP SF *translog* model for Falkland hake can be expressed using the above symbols and variables in abridged notation, with inputs in logarithmic form $lnx_{it,k}$, and omitting the second-order terms $[\ln x_{it,k}]^2$ (which turned out to have statistically insignificant parameters in regression results):

$$\ln hake_{it} = \alpha_i + \Sigma_k \beta_{ki} \ln x_{it,k} + (1/2)\Sigma_k \Sigma_g \beta_{kg} \left[\ln x_{it,k} \ln x_{it,g}\right] + \beta_4 \ln rockcod_{it} + \delta_t t + \delta_{ifs} Illex\text{fs} + \delta_{itq}\text{ITQ} + \delta_{lic}\text{Lic} + \varepsilon_{it} \quad (1)$$

$$a_i = \alpha + \beta_m m_i + (1/2)\beta_{mm} {m_i}^2 \quad (2)$$

$$\beta_{ki} = \beta_k + \beta_{km} m_i \quad (m_i \sim N[0, 1]) \quad (3)$$

$$\varepsilon_{it} = v_{it} - u_{it} \quad \left(v_{it} \sim N\left[0, {\sigma_v}^2\right], u_{it} \sim N^+\left[0, {\sigma_u}^2\right]\right) \quad (4)$$

[4] Skipper effects arise from multiple abilities, concerning among others (a) finding the best fishing grounds, (b) interpreting the sea and its ecological environment, including seasonal variations in resource abundance and (c) leading and managing the crew. Since these skills incorporate elements of technical change, a production model accounting for latent management effects can relax the restrictive assumption of Hicks-neutrality on technical change (i.e. not affecting the marginal rate of substitution between each pair of inputs).

The model implies that TE is measurable in terms of a time-invariant individual effect (Eq. (2)) and time-varying interaction effects of input use with skipper skills (Eq. (3)). Since some elements of the random parameters are likely to be collinear with the explanatory variables, Alvarez et al. (2005) propose to include group means of these variables (as in *correlated random effects* models), so as to filter out this possible source of parameter bias. Following Mundlak (1978), for a given vessel i, one can decompose m_i between an uncorrelated random term w_i and another component that is correlated with observable covariates. Relative to the latter, assuming—restrictively, to avoid identification problems—equal correlations across time reference units, parameters (vector ζ_k in Eq. (5)) of average values of lags and leads of $\ln x_{\mathrm{it}}$ account for linear correlations between inputs and latent management heterogeneity. The above model is thus augmented as follows[5]:

$$m_i = \zeta_k{}' \left[\Sigma_k (\Sigma_t \ln x_{\mathrm{it}} / T)_k\right] + w_i \quad (w_i \sim N[0, 1]) \tag{5}$$

Finfish prices, consumer markets, and threshold responses in market chains

Assume fishery management to be in a position to control the level of fishing output at an economic optimum. Provided one does not exceed a maximum sustainable yield, this level will be where marginal social cost equals marginal revenue, i.e. demand for the fish product. If divergences between social and private costs are ignored, maximum economic yield is attained at a point where marginal costs equal marginal revenues (Harris 2002, p. 282). Fish export prices of a small and remote economy relying on foreign markets, will reflect the performance of competing suppliers, marketing strategies of wholesalers and retailers in consumer markets, and price determinants related to product quality, shipment costs, and economic agents' information (Quezada and Dresdner 2014; Chami Batista and da Silveira 2010; Kuiper et al. 2003; Rapsomanikis et al. 2003). Among fishing vessels, some are more technically efficient, thus earning intra-marginal rents, namely economic profits over and above the least profitable vessel (Coaglan and Pascoe 1999).

Drawing on and adapting to this framework models of commodity market integration (Asche and Tveterås 2008), long-run price equilibrium of Falkland hake in the Spanish market can be written as:

$$p_{fh(t)} = a^* \, p_{fo(t)}{}^{\eta*} p_{s(t)}{}^{\beta*} Q_{s(t)}{}^{\gamma*} p_{m(t)}{}^{\delta*} p_{p(t)}{}^{\xi*} \left[W_{(t)}{}^{\phi*}\right] e^{\nu} \tag{6}$$

where ν is a random error term, with e the exponential function. The subscripts indicate import prices of frozen hake (*fh*) and other finfish (*fo*) from the Falklands, frozen hake import prices and landings from major suppliers of southern Atlantic hakes (*s*), and prices of fresh hake of local market traders (*m*) and at main local ports (*p*). Transfer and

[5] In unbalanced panels, unit 'selection'—units fully versus not fully observed over the sample period—may itself be correlated with unobserved heterogeneity and the covariates. Revisions of Mundlak's approach have tried to redress this problem (Wooldridge 2010). However, relative to the Falkland finfish fishery, the size of unbalanced panel periods (T_i) across vessels does not systematically depend on licence types, among others.

transaction costs (W), whose information is not explicitly available, are often assumed to be either constant or a constant proportion of nominal product prices, and therefore not modelled as a separate variable. Some studies attribute short-run deviations from complete commodity arbitrage to transport costs and other 'residual' factors such as lack of full product homogeneity (Goodwin 1990). However, in view of geographical remoteness and technical requirements for handling and storage of frozen fish products, it is worth testing the possible indirect impact of backlogs in TE of Falkland finfish vessels, by using average technical inefficiency estimates as a proxy indicator for these residual factors.

To test APT in the Spanish hake value chain (with asymmetric adjustments by retailers), one can check for threshold non-linearity through a TAR estimation on residuals (ε_t) from the long-run equilibrium equation of log-transformed retail prices (with θ a vector of long-run elasticity coefficients: $\theta = \rho^*, \zeta^*$). Assume this equilibrium equation as follows:

$$p_{r(t)} = \omega^* {p_{s(t)}}^{\rho^*} {p_{w(t)}}^{\zeta^*} e^{\varepsilon} \tag{7}$$

where the subscripts denote import prices of frozen hake from major suppliers of southern Atlantic hakes (s) and prices of fresh hake in the local market chain (retail (r), wholesale (w)). To this purpose, TAR models can help identify (i) asymmetry in terms of intercept and autoregressive terms in the log-differenced equation and (ii) asymmetry in the effects of price shocks, expressed as deviations from a long-run stable level relationship. Beyond these specific applications, Hansen (2011) provides an overview of TAR models in theoretical and empirical economics.

The first approach focuses on *asymmetric short-run shock dynamics* in an otherwise homogenous long-run equilibrium (Appendix 2: Eq. (8a)). This dynamics is testable for dependence on short-term deviations from equilibrium, by using the lagged error correction term (z_{t-1}) as regime-change signal (defined as *threshold variable*: q_t in Appendix 2). For instance, given a two-regime framework, if in Eq. (8a) $\varphi_{1j} < 0$ for $z_{t-1} < 0$, and $\varphi_{1j} \cong 0$ for $z_{t-1} > 0$, short-run retail market responses are relatively quick in adjusting to upward shifts in e.g. wholesale prices, in contrast with downward price stickiness in the opposite situation. This downward rigidity, defined as 'positive' APT, concerns short-run shocks from the equilibrium.

This first type of asymmetry may or may not coexist with asymmetry in strength of equilibrium readjustments to a long-term attractor. Relative to the latter, the second approach allows testing, through a revised Augmented Dickey Fuller (ADF) test on residuals from the regression in levels, for *cointegration with threshold non-linearity* (Nakajima et al. 2011; Enders and Granger 1998). Signalling of regime shifts is captured through either steepness (in levels, as in Eq. (8b) if once again $q_t = z_{t-1}$ and the autoregressive process is of first order), or deepness (/sharpness, in differences: $q_t = \Delta z_{t-1}$), e.g. in finfish price residual 'cycles'. A threshold variable in differences implies that the asymmetric market behaviour depends on rates of change in the long-run equilibrium error. Hence, with the acceleration rate, not the level, of price shocks as a driving factor, the sharpness-related specification is defined *momentum*-TAR (M-TAR; Enders and Siklos 2001).

Data and econometric results

Data and variables

Falkland finfish fisheries

The Falkland finfish fishery consists of 48 trawler vessels, owned or hired by 25 companies. All licenced vessels are legally required to provide details on catch and fishing effort. This information is subject to surveillance procedures, including a satellite vessel monitoring system, which has been fully operating since 2008. For this analysis, catches by fishing vessels concerned the January 2008–July 2016 monthly series from the Falkland Islands government fishery database. In the resulting unbalanced panel of 2290 observations, nearly 42% of catch records came from ‘restricted finfish’ licences, 29% from unrestricted ‘finfish’ licences (with hake as fish target), 19.3% from licences for restricted finfish plus *Illex* squid and 9.5% from licences for skates and rays.

Relative to hake, rockcod and *Illex*, registered catches per vessel/month amounted to nearly 49, 157 and 39 tonnes over the sample period, respectively. In a few successful seasons, catches substantially exceeded these amounts—up to more than tenfold for *Illex* and hake. However, one should notice that, relative to some observations, catch records corresponded to fishing trips finalised after more than 1 month, thus implying overlaps with the previous month. On average, vessels spent slightly less than 2 weeks at sea, with fishing trips registered as completed on a monthly basis, in terms of *final total* number of fishing hours at sea, lasting from as short as 4 h up to 1.5–2 months. Only nine vessels reported not more than one fishing trip per month (including one targeting skates and rays, and another with A-Y licences). All other vessels had some—albeit rare—monthly records with two trips or, limited to four records—occurring once to four vessels—three trips. These trips used different licences, with catch and fishing effort records treated as distinct observations.[6]

As in *translog* equations, catch and input variables are in log-transformed form, which partly redresses rightward skewness and leptokurtosis for some of these variables, as observable in summary statistics (Table 1). As often found in fishery production studies, attributes of fishing vessels (gross registered tonnage, vessel length, engine power, crew size) are highly collinear (with correlation coefficients ranging between 0.6 and 0.8). Due to multicollinearity problems, this analysis used only crew size and gross tonnage as near-fixed inputs, without inclusion of an interaction term.

Import and consumer market

The second part of the analysis relied on Eurostat external trade statistics of Spanish imports of frozen hake and other finfish from the Falklands and the two main south

[6] Vessel records with catches and fishing time spent at sea corresponding to more than—mostly just exceeding—30 days represent nearly 8% of the sample, and follow a slight bimodal pattern with peaks in May and October. If added to regression specifications of the pooled SF and LVRP SF[2] models including time effects (Table 2), an intercept dummy accounting for these records suggests no statistically significant difference from the rest of the sample. Stochastic frontier regressions were estimated using Limdep 10/NLogit 5 and cointegration and TAR models with EViews 9 (IHS 2015; Greene 2012).

Atlantic exporters, along with statistical information on the Spanish market of fresh hake supply and consumption (harbour, wholesale and retail prices: month-averaged weekly data; www.magrama.gob.es/es/alimentacion). As from January 2012, a new harmonised classification coding system came into effect, with greater level of detail. For consistency with the 2007 classification, this study used the aggregate category throughout the period analysed (April 2004–2016), with frozen fish export subcategories from the Falklands reported as 'other frozen finfish' (World Customs Organisation, Table II, www.wcoomd.org). Relative to both datasets, variables are listed under Table 1.[7]

Over the period analysed, frozen hake sales from the Falklands to Spain amounted to nearly one third of the respective sales from Argentina and Namibia. Particularly in the first few years of the sample period, Falkland hake prices traced substantial variations, with two intra-annual seasonal upward movements, from March to May and from October/November to January (Fig. 1, euro price per kg). Fresh hake prices in Spain similarly experienced high instability, with calendar effects in coincidence with December peaks, as typical of other hake consumer markets (Floros and Failler 2004). Relative to south Atlantic finfish at Spanish ports, sales quantities underwent greater market instability than prices. In turn, sales of hake and other finfish from the Falklands were substantially more unstable than hake sales from the two major south Atlantic exporters, as suggested by coefficients of variation over partly overlapping sub-periods (Table 1: *Hake sale* vs. *Hake sale Arg./Nam.*; corresponding to rolling windows B and D1/2 in Table 4). Relative to Argentine and Namibian suppliers, Falkland vessels are largely price-takers. However, the performance of Falkland hake exports to Spain shows no clear-cut patterns in terms of either prices versus sales, or the latter vis-à-vis those from Argentina or Namibia (Fig. 2).

Stochastic frontiers and technical inefficiency

Table 2 reports econometric results from LVRP SF regressions of Falkland hake catch by fishing vessel, estimated by maximum simulated likelihood (MSL) through 200 Halton draw iterations, under assumption of normally distributed random parameters. For the sake of comparison, the table also reports ML estimates from a pooled model with no latent skipper effects. Regression diagnostics for this model support the use of a stochastic frontier, with rejection at 1% statistical significance of both null hypotheses of lack of normalised residual skewness (Coelli 1993; χ^2 version: Greene 2012) and systematic inefficiency component u_{it} in the error distribution (Kodde and Palm 1986).

In stochastic frontier regression, a 'signal-to-noise' ratio λ reflects the relative importance of inefficiency over random disturbances, in terms of standard errors ($\sigma_{\mathrm{u}}/\sigma_{\mathrm{v}}$). Estimates of this ratio point to high heterogeneity in vessel inefficiency (Table 2). In terms of explanatory power and maximum likelihood (ML) model selection, no substantial differences stand out between alternative model formulations (Table 2: pseudo-R^2 and AIC/N). However, LVRP SF turns out to be more appropriate than a conventional stochastic production frontier *translog* model: the estimated coefficients

[7] Apart from those unrelated to Falkland finfish, these subcategories included southern blue whiting, rays/skates, and finfish for other species jointly classified. Prior to the period analysed, over 2001–2003, some months recorded no finfish landings from the Falkland Islands at Spanish ports.

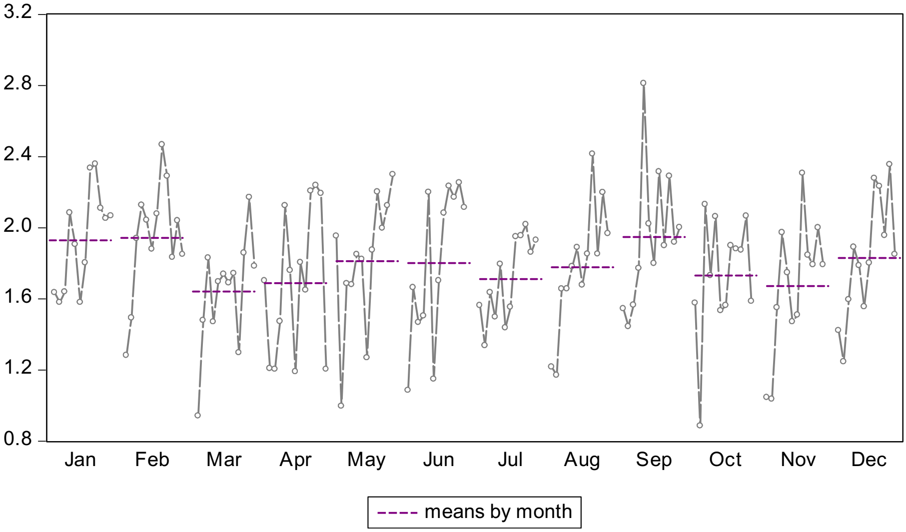

Fig. 1 Price of Falkland frozen hake sold at Spanish harbours: patterns by month (euro per kg, April 2004-April 2016)

β_{km} (Table 2: *inputs · skipper skill*) and β_m are statistically significant at 1% level, except for β_m in model SF[1], and this also applies to the three auxiliary parameter estimates of input 'group means'. This suggests that hake catch coefficients have tended to change with level of fishing management, with the latter preferably modelled through Mundlak's adjustment (Table 2, SF[2]: ζ_k). The impact on catches of latent skipper skills appears to be positive through its interactions with crew numbers, and negative through its interactions with gross vessel capacity and—limited to the adjustment-augmented model—with fishing effort (Table 2, SF[2]: β_{km}).[8]

Based on mean random parameters of input variables, the LVRP SF models indicate a high positive 'direct' mean elasticity of hake catches to fishing time spent at sea (Table 2: $\beta_2 \cong 1.9$ in SF[2]). In graphical terms, a heterogeneous pattern is also observable from the related scatter diagram (Fig. 3, logtransformed data). Relative to crew size and vessel cargo-carrying capacity and apart from some collinearity between these variables, cross-model differences in sign, size, and statistical significance of direct elasticity parameters partly depend on whether or not Mundlak's adjustment is used. Skipper skill effects, measured by the semi-elasticity parameter β_m, appear to be positive and stable across vessels: absolute marginal improvements in level of managerial ability yields more than proportional increases in production ($\beta_2 \cong 1.5$ in SF[2]), without further—declining or strengthening—effects (β_{mm} of management squared is not statistically significant).

[8] Negative interaction term parameters do not have a thorough negative interpretation (Alvarez et al. 2005). Given a single output (y_{it}) and following the definition of output-oriented TE, $\ln y_{it} - \ln y_{it}{}^{*} = - u_{it} = \ln \mathrm{TE}_{it} = \beta_m(m_i - m_i^{*}) + 1/2\, \beta_{mm}(m_i^{2} - m_i^{*2}) + \beta_{km}(m_i - m_i^{*})\ln x_{it}$. Since $\partial(-u_{it})/\partial \ln x_{it} = \partial \ln \mathrm{TE}_{it}/\partial \ln x_{it} = \beta_{km}(m_i - m_i^{*})$ and, for most vessels, $m_i < m_i^{*}$, for given managerial skills an increased use of an input enhances TE only if $\beta_{km} < 0$ (even if this smooths down, by LVRP SF model construction, a possible positive 'direct' elasticity [β_k] effect of input use on actual output). In a *translog* regression, parameters should be interpreted with due caution. For instance, in the pooled SF model (Table 2), given the log-transformed variables listed under Table 1, catch elasticity to fishing time at sea is given by $\eta = \beta_2 + \beta_{12}\mathrm{Crew} + \beta_{23}\mathrm{GRT}$, which is evaluated at sample mean (Kumbhakar and Wang 2005).

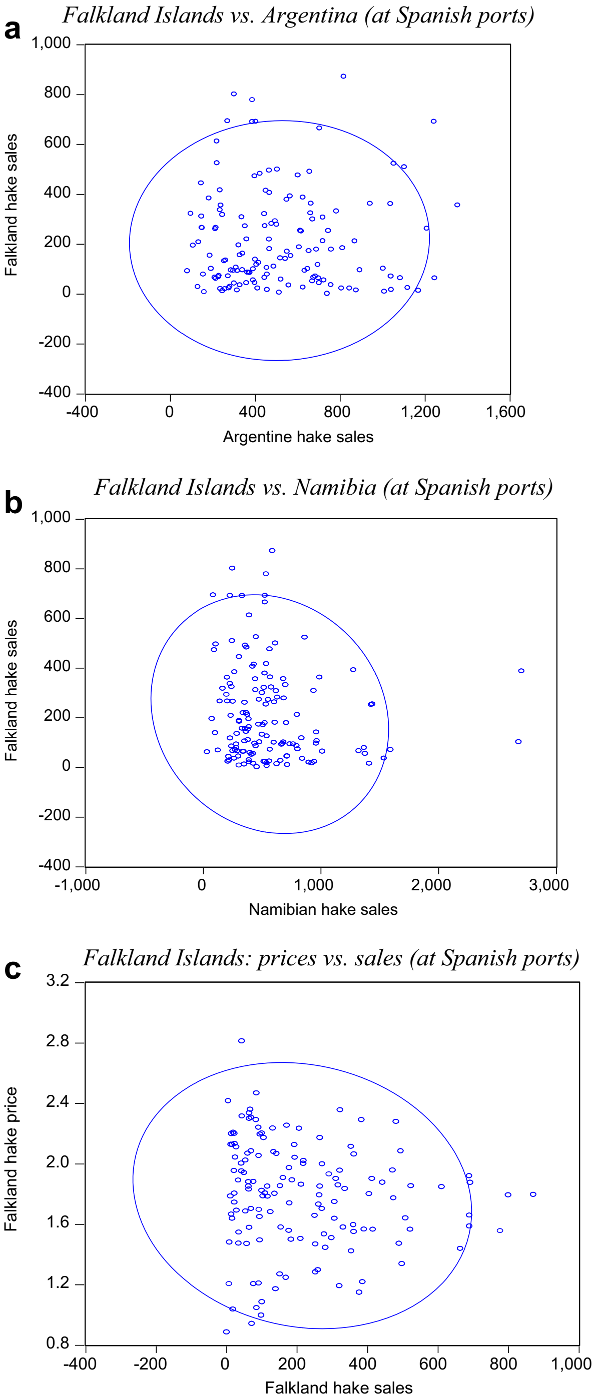

Fig. 2 Spanish imports of frozen hake (95% confidence ellipses, April 2004–December 2016) 95% confidence (F-distributed) ellipse regions around means (frozen hake imports from the Falkland Islands, Argentina, and Namibia, tonnes; import price of Falkland frozen hake, euro/kg)

Table 2 Estimated frontier models (Falkland hake catches, January 2008–July 2016)

Variable	Parameter	Pooled SF	Latent variable-random parameters stochastic frontier (LVRP SF)				
			SF[1]		SF[2] (with group means)		
			Means of random parameters $\mu(\beta_k)$	Inputs · skipper skill (β_{km})	Means of random par. $\mu(\beta_k)$ [ζ_k par. of group means of inputs]		Inputs · skipper skill (β_{km})
Constant	α	− 1.5 (− 0.39) *− 4.64 (− 1.23)*	− 5.62 (− 1.37) *− 4.28 (− 1.33)*		− 6.01 *5.22* (− 0.72) *(0.63)*		
Crew	β_1 (β_{1m}) [ζ_1]	− 4.95 (− 4.43)***	− 5.75 (− 5.68)***	0.55 (2.75)***	11.5 (1.36)	*[− 12.0] (− 3.53)****	0.49 (2.65)***
Effort	β_2 (β_{2m}) [ζ_2]	1.03 (1.5)	1.56 (2.14)**	0.1 (3.09)***	1.92 (2.27)**	*[0.73] (3.14)****	− 0.1 (− 2.85)***
GRT	β_3 (β_{3m}) [ζ_3]	2.63 (4.59)***	3.54 (6.55)***	− 0.41 (− 3.45)***	− 2.62 (− 1.15)	*[3.49] (2.00)***	− 0.24 (− 2.85)***
Skipper skill							
m_i	β_m			0.07 (0.1)			1.5 (2.84)***
m_i^2	β_{mm}			− 0.07 (− 1.34)			0.04 (1.35)
Interaction and control variables							
Effort · Crew	β_{12}	0.64 (3.17)***	0.71 (3.86)***		− 0.44 (− 0.87)		
Effort · GRT	β_{23}	− 0.31 (− 2.99)***	− 0.41 (− 4.15)***		− 0.09 (− 0.4)		
Rockcod	β_4	− 0.12 (− 8.03)***	− 0.12 (− 8.57)***		− 0.12 (− 7.78)***		
Licence F	δ_f	− 1.69 (− 17.9)***	− 1.55 (− 18.2)***		− 1.4 (− 13.5)***		
Licence G	δ_g	− 1.36 (− 13.7)***	− 1.27 (− 10.2)***		− 1.23 (− 9.45)***		
Licence WZ	δ_{wz}	− 1.1 (− 17.5)***	− 1.17 (− 19.1)***		− 1.12 (− 17.5)***		
*Illex*fs	δ_{ifs}	0.52 (5.45)***	0.45 (4.04)***		0.44 (3.96)***		
Trend (months)	δ_t	− 0.05 (− 2.94)***	− 0.03 (− 2.64)***		− 0.03 (− 2.69)***		
ITQ	δ_{itq}	*0.29 (5.00)* ***	*0.32 (6.24)* ***		*0.37(7.28)****		
Isl. S. Georgia	δ_{sg}	*0.43 (7.33)* ***	*0.49 (10.8)* ***		*0.48 (10.8)****		
λ		4.15 (16.3)***	4.16 (14.2)*** *4.49 (11.8)* ***		4.31 (12.7)*** *4.78 (13.02)****		

Table 2 (continued)

Variable	Parameter	Pooled SF	Latent variable-random parameters stochastic frontier (LVRP SF)			
			SF[1]		SF[2] (with group means)	
			Means of random parameters $\mu(\beta_k)$	Inputs · skipper skill (β_{km})	Means of random par. $\mu(\beta_k)$ [ζ_k par. of group means of inputs]	Inputs · skipper skill (β_{km})
σ_u		2.11	1.99		2.001	
σ_ε		2.17***	2.05 (63.8)*** *2.02 (68.7)****		2.05 (59.9)*** *2.03 (70.03)****	
Regression model diagnostics						
Sk. $\chi^2(1)$		199.9*** *(244.2***)*				
KP $\chi^2(1)$		274.1*** *(315.3***)*				
AIC/*N*		3.35 *(3.3)*	3.125 *(3.07)*		3.12 *(3.07)*	
Ps.R^2 ρ_0 *[ρ_p]*		0.183 *(0.196)*	0.201 *(0.216) [0.022]*		0.203 *(0.217) [0.024]*	
N		2181	2181 *(n = 48)*		2181 *(n = 48)*	
Inefficiency estimates (u_r, u_{ur}: SF models with (*r*)/without (*ur*) zero parameter restrictions on ITQ and Isl. South Georgia)						
Summary stat. u_r (u_{ur})	min.	0.16 (0.16)			0.12 (0.13)	
	mean	1.52 (1.47)			1.57 (1.54)	
	max.	2.97 (2.86)			6.96 (7.296)	
$\rho(u_r, u_{ur})$		0.98			0.97	

Dependent variable (in nat. log.): Hake. In parentheses are t statistics. In italics are (a) ζ_k parameters with t statistics associated with time means of inputs (LVRP SF[2]) and (b) parameters with t statistics (limited to random constant and the two time dummies) and regression diagnostics for SF model specifications including time effects (*ITQ*, *Isl. South Georgia*). Signal-to-noise ratio $\lambda = \sigma_u/\sigma_v$ (ε_{it} two-component error term ($= v_{it} - u_{it}$)). Pseudo-R^2 (McFadden) likelihood ratio index includes the following: (a) fitted SF panel data vs. intercept-only log-likelihood (with $\sigma_u = 0$): $\rho_0 = 1 - [\ln L/\ln L_0]$ and (b) (in brackets/italics) fitted SF panel data vs. pooled SF log-likelihood includes the following: $\rho_p = 1 - [\ln L/\ln L_p]$

Sk χ^2 *(1)*, Coelli χ^2 test on zero skewness in residuals; *KP* χ^2 *(1)*, Kodde-Palm-mixed χ^2 Wald test on boundary parameter ($\sigma_u = 0$ vs. $\sigma_u > 0$); *AIC*, Akaike Information Criterion; *N*, panel sample size; *n*, number of fishing vessels

*$p \leq 0.10$; **$p \leq 0.05$; ***$p \leq 0.01$

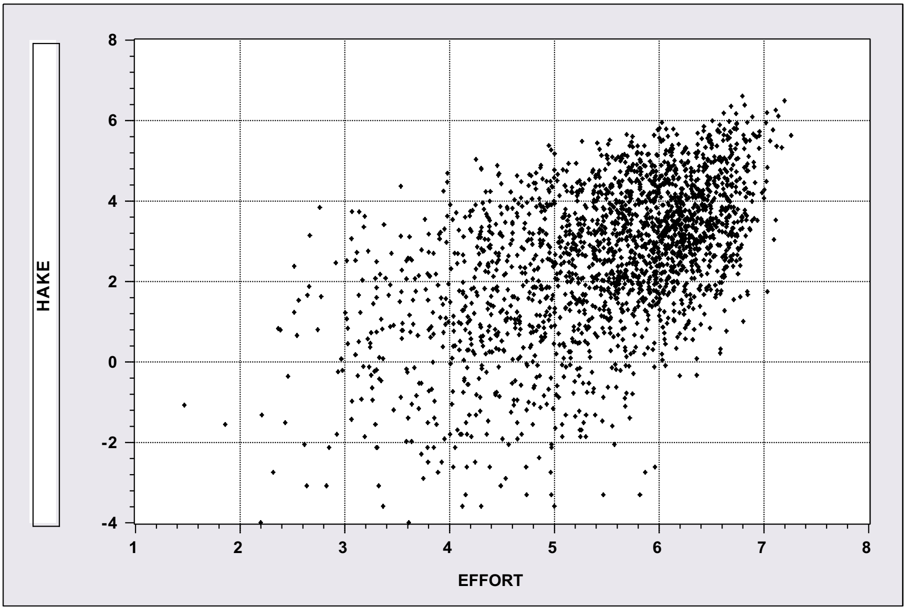

Fig. 3 Scatterplot of hake catches and fishing effort (log-transformed data, January 2008-July 2016: list of variables under Table 1)

As for the control variables, other conditions unchanged, hake and rockcod turn out to partly offset each other across vessels and over time, with, e.g. 10% catch increases in rockcod coupled with 1.2% declines in hake on average (Table 2: β_4). During the *Illex* season (Appendix 1), vessels in the Falklands appear to benefit from accrued conditions within which hake can be caught: based on SF[2] results, moving from out-of-season to season brought about nearly a 55% increase in hake catches (= exp(δ_{ifs}) − 1). Similarly, other conditions unchanged, the estimated parameter of the intra-annual monthly trend suggests declining rates of hake catches along a calendar year (Table 2, SF[2]: δ_t; SF[2] yields MSL convergence problems if the trend variable is omitted from the regression specification).

Expectedly, fish licence categories not allowing hake as a main target led to substantially lower catches than what achieved by vessels operating under A-Y licences (implicit category in the regressions). Average shortfalls ranged between − 67 and − 75%, based on SF[2] dummy parameters (= exp(δ_{lic}) – 1, for *lic* = W-Z and F, respectively (δ_{wz} and δ_f), with δ_g in between). Time effect dummies to account for entry into effect of the ITQ regime and later upgrades of part of the fishing fleet, are associated with upward-shifts in the production frontier (Table 2: ITQ, Isl. South Georgia). However, inefficiency estimates have virtually identical descriptive statistics as those obtained from pooled SF and (LVRP) SF[2] regressions without these dummies, with high linear correlations between these estimates within either of the two model formulations (Table 2, u_r vs. u_{ur}: summary statistics and $\rho(u_r, u_{ur})$).

Finfish fishery inefficiency estimates from the two (conventional versus latent effects) approaches were highly correlated ($\rho \cong 0.9$) but yielded different vessel inefficiency distributions. In the pooled SF regression, u_{it} traces a bimodal density. By contrast, the LVRP SF regression with Mundlak's adjustment produces an inefficiency density with a

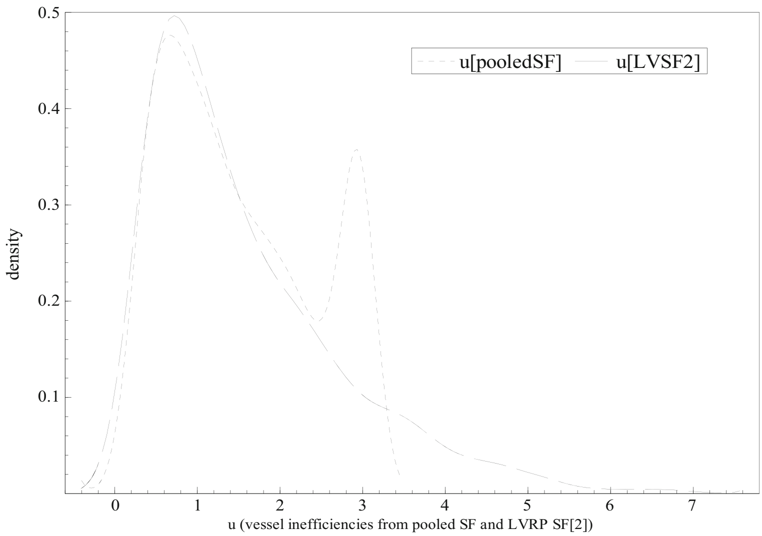

Fig. 4 Kernel density estimates of technical inefficiency across fishing vessels Inefficiency estimates (u_{it}): pooled SF (dotted), LVRP SF[2] (long-dashed) (estimation results in Table 2)

less tight, rightward-skewed unimodal shape (Fig. 4). This result only partly matches expectations of less inflated inefficiencies compared with stochastic frontier models with no latent management effects and is robust to the inclusion of above two dummies accounting for fishery regulatory changes. Nonetheless, it does highlight the suitability of LVRP SF to capture unobserved heterogeneity and multiple frontiers.

Conversion of model estimates to TE Debreu-Farrell measure, which ranges between zero and one, yields nearly equivalent mean TE levels in both approaches ($\mu_{TE} \cong 0.21$). However, the LVRP SF model yields a relatively wider spread between the most and least efficient catch monthly records by fishing vessels (with TE maximum values equal to 0.89 and 0.85, and minimum values to 0.001 and 0.051, for SF[2] and pooled SF regression respectively).[9] Except for individual right-tail observations in the inefficiency score distribution of SF[2], no systematic TE differences are noticeable across fishing trawlers and companies. Once higher production frontier of A-Y licence holders is accounted for, vessels using these licences were relatively farther from the frontier than those using other licences relative to their frontiers. This holds over the period as a whole and two (out of three) 2.5- to 3-year sub-periods (Table 3: *u[LV2a]* vs. *u[LV2n]*; see note at bottom of the table and list of variables under Table 1).

[9] Given a set of inputs x, a set of outputs y, a set of input requirements $L(y)$, and $\theta \in (0,1)$ the proportion of radial contraction of an input vector needed to reach the efficient isoquant, Debreu-Farrell input-oriented measure of technical efficiency is defined as $TE = \min(\theta : \theta_x \in L(y)) \leq 1$ (Greene 2007; Farrell 1957). Stochastic frontier regressions estimate inefficiency as $u_i = -\ln(TE_i)$ ($\approx 1 - TE_i$), thus tending to overstate this measure: estimates are slightly higher than actual radial distance for points closer to the efficiency frontier but more inflated for more inefficient points (e.g. with $1 - TE_i = 0.3$, $u_i = 0.36$; with $1 - TE_i = 0.7$, $u_i = 1.2$).

Hake sales and asymmetric price adjustments

Unit root and bounds testing for long-run relationship

Issues of market integration and vertical/horizontal fish price transmission have mostly been analysed through either (i) a bivariate cointegrating approach, with or without a residual-based test for regime shifts (Regnier and Bayragmoglu 2016) or (ii) a multivariate systems approach (Asche et al. 2007a, b). The latter is suited to check for endogeneity and causality in price changes, when price variables are non-stationary in levels and stationary in differences. However, this modelling approach is subject to small sample bias and unclear interpretation in the presence of stationary variables in levels (Lee 2012). In this study, unit root tests did not provide unequivocal indications on whether the variables are trend-stationary, difference-stationary, or even integrated of higher order.

The ADF test rejected the null hypothesis of *non-stationarity* for five out of seven log-transformed price variables. Relative to the two remaining variables, the test rejected the null only for log-differences (Table 3: price variables). The DF-GLS test, namely DF test with GLS detrending (Elliott et al. 1996), yielded similar results, but it failed to reject the null also for the price in log-differences of frozen hake imported from the Falklands.[10] In contrast, the KPSS χ^2 LM test rejected the null of *(trend-)stationarity* at 5 or 10% statistical significance, for all price variables except Argentine hake (Table 3: *Hake price Arg.*; Kwiatkowski et al. 1992). As for landings of hake and other finfish, and Falkland vessel log-transformed average technical inefficiencies obtained from individual vessel estimates of the SF[2] model, most unit root tests suggested stationarity in levels, except once again for the KPSS test in four—out of seven—cases, for which the null of stationarity was rejected (Table 3).

In the presence of mixed evidence from unit root tests, a more suitable, two-step approach to cointegration analysis relies on an autoregressive distributed lag-Schwarz Bayesian Information criterion (ARDL-SBC: Pesaran et al. 2001; Pesaran and Shin 1999). Absence of long-run cointegrating relationship between dependent and explanatory variables implies a joint zero null hypothesis on the coefficients of level variables in an unrestricted ARDL model rearranged as an error-correction formulation (in differences and levels; note 10). The test relies on two sets of asymptotic non-standard critical values, which reflect two extreme cases in the lagged equilibrium-correction mechanism, with all regressors integrated of order zero or one ($I(0)$ or $I(1)$). The critical value bounds account for the in-between case of variables with mixed orders of integration, with scope for inconclusive inference. If the F_{PSS} statistic falls outside the bounds, one can draw statistical inference without knowing the levels of integration of the variables. The test is robust to endogeneity and cointegrating relationships among regressors, as well as possible short-run reverse causality (Hassler and Wolters 2006; Pesaran et al. 2001). The latter is unlikely in this study, given price-taker conditions of Falkland finfish fisheries.

To capture changes in market chain price transmissions and check model stability, rolling window regression is a potentially more robust and informative modelling approach than

[10] As the ADF test, this test is sensitive to sample size and order of autoregressive lags, with MacKinnon critical values geared to redress the problem (MacKinnon 1996; Cheung and Lai 1995). Relative to the ARDL-SBC cointegration approach, an error-correction model is derivable from rearranging and re-parameterising a dynamic ARDL model in levels (Harris 1995, pp. 23–25).

Table 3 Unit root test results and average inefficiency estimates

Price variables		Hake price	Hake pr. Arg.	Hake pr. Nam.	Other finfish price	Harbour price	Retail price	Wholesale price
$\tau\ [y_{-1}]$	ADF	− 1.89(4)	− 8.9(0)***	− 8.6(0)***	− 8.2(0)***	− 5.38(0)***	− 2.52(0)	− 5.84(0)***
	DF-GLS$^{\tau}$	− 2.00(4)	− 8.89(0)***	− 4.81(1)***	− 8.21(0)***	− 5.35(0)***	− 2.47(0)	− 3.24(2)**
$\chi^2\ [y_{-1}]$	KPSS	0.13*	0.05	0.15**	0.12*	0.2**	0.15**	0.21**
$\tau\ [\Delta y_{-1}]$	ADF	− 11.5(3)***					− 11.2(0)***	
	DF-GLS$^{\mu}$	− 0.48(8)					− 10.4(0)***	
$\chi^2\ [\Delta y_{-1}]$	KPSS	0.21	(0.05)	0.25	0.24	0.02	0.05	0.03
Quantity variables (/average inefficiencies)		Hake sale	Hake sale Arg.	Hake sale Nam.	Other finfish sale	*U*[LV2*a*]	*U*[LV2*n*]	*U*[LV2μ]
$\tau\ [y_{-1}]$	ADF	− 10.9(0)***	− 4.12(2)***	− 10.1(0)***	− 11.1(0)***	− 8.99(0)***	− 8.06(0)***	− 8.35(0)***
	DF-GLS$^{\tau}$	− 10.7(0)***	− 3.9(2)***	− 5.6(1)***	− 1.84(5)	− 6.93(0)***	− 7.57(0)***	− 3.15(1)**
$\chi^2\ [y_{-1}]$	KPSS	0.06	0.14*	0.05	0.29***	0.13*	0.06	0.13*
u[LV2i]	*u*[LV2*a*]				*u*[LV2*n*]			
	January 2008–July 2016	January 2008–December 2010	January 2011–December 2013	January 2014–July 2016	January 2008–July 2016	January 2008–December 2010	January 2011–December 2013	January 2014–July 2016
Mean	1.68	1.81	1.49	1.76	1.52	1.54	1.56	1.45
Median	1.55	1.71	1.43	1.6	1.48	1.58	1.49	1.33

ADF and KPSS test regressions: with intercept and linear trend for log-transformed level variables (y) and with intercept (without linear trend) for log-differenced variables (Δy). In parentheses are lag order in ADF and DF-GLS equations, chosen based on Schwarz Bayesian Information Criterion (SBC). U[LV2i] = ln(u[LV2i]), with u[LV2i] = technical inefficiency estimates from LVRP SF[2] (Table 2), by licence type (vessel operating with: $i = a$ A-Y licence (unrestricted 'finfish'); $i = n$ F, G or W-Z licence; $i = \mu$ mean of (a) and (n) values)

DF-GLS$^{\tau(/\mu)}$, modified ADF test (locally demeaned series with (τ)/without (μ) linear trend; Elliott et al. (1996)

*$p \leq 0.10$; **$p \leq 0.05$; ***$p \leq 0.01$

estimations based on a full sample (Nakajima et al. 2011). Recursive regressions with shifting start and end observations by fixed window can be especially useful if a sample period suffers from data limitations (see note 7). In this analysis, vessel inefficiency estimates are only available from January 2008, which happens to anticipate slightly the mid-2008 turbulence in global commodity markets. Tables 4 and 5 present selected regression results, concerning full period and rolling window sub-periods, relative to Falkland frozen hake prices and Spanish retail prices of fresh hake, respectively.[11]

Rolling regression diagnostics and parameter estimates

Full-sample ML estimation yielded F_{PSS} bounds-test results in the indeterminate in-between region. Moreover, even if rolling-window regressions do not fully redress these problems, full-sample residuals indicated patterns of autocorrelation, volatility clustering and/or non-normality (AR, ARCH, and, for model A, Jarque-Bera test; Tables 4 and 5: A and E). Relative to Falkland finfish exporters and Spanish retailers, F_{PSS} tests on rolling-window regressions fail to reject the hypothesis of no long-run cointegrating relationships for the first window sub-period, thus suggesting no common long-term equilibria in fish market supply and price co-movements, with weak statistical inference from the respective models (models B and F1). Conversely, the tests reject this hypothesis for subsequent sub-periods, which may reflect an increasing market integration of Falkland finfish vis-à-vis major south Atlantic suppliers, and of retailers vis-à-vis upstream chain segments in the Spanish hake market (models C, D1 and F2).

In terms of both short- and long-run dynamics, parameter estimates support the hypothesis of low cross-price responses of Falkland hake vis-à-vis finfish other than hake exported to Spain. Falkland hake prices appear as largely inelastic or only marginally responsive to Spanish imports from Argentina and Namibia. However, the latter country turns out to exercise some degree of price 'leadership' in terms of frozen hake for Falkland exports, with this influence tending to increase over time in terms of short-term adjustments and long-term impacts (Table 4: *ΔHake price Nam.*, *Hake price Nam.*). As discussed in Sect. 2, a number of factors can contribute to this outcome, including quality of partly differentiated frozen hake products and transport costs. Regarding these costs, distances to Vigo—major port-of-entry in Spain for long-distanced fishing fleets operating in Falkland seas—from Walvis Bay (Namibia), Buenos Aires and Stanley/Falklands amount to 4713, 5512 and 6197 nautical miles, respectively. For a freezer-factory trawler with speed of 10 knots, this implies nearly 20, 23 and 26 days for shipment delivery, respectively from the three ports of origin (National Geo-Spatial Intelligence (NGA) 2001; sea-distances.org).

Marginal but statistically significant changes occur in coincidence with seasonal hake import price slowdowns in March and October (*Post1*). Improvements in TE of finfish vessels operating in the Falklands appeared to have no influence in terms of sale prices at Spanish ports: on the contrary, there seems to have been a trade-off between lesser average vessel inefficiency and higher market prices for Falkland vessels with unrestricted finfish licences (model D2: *ΔU[LV2a]*, *U[LV2a]*). This result is sensitive

[11] Lag orders were chosen based on SBC for model selection of ARDL specifications, with up to three lags for endogenous variable and regressors. For space reasons, first-step ARDL estimates are not reported, and the same applies to short-run parameters if statistically insignificant and/or associated to autoregressive terms. As a possible limitation, the second-step ARDL-SBC regression may contain over-differenced regressors, if some of the variables are stationary in levels.

Table 4 Long-run coefficients and market equilibrium adjustment (Falkland hake price: total sample period and rolling window)

Estimation period	April 2004–April 2016	April 2004–December 2012	January 2006–December 2014	January 2008–April 2016	January 2008–April 2016
	A	B	C	D1	D2
Cointegrating regression					
ΔHake price Nam.	0.28 (2.16)**	0.16 (0.9)	0.25 (1.82)*	0.3 (2.04)**	0.44 (2.64)***
ΔOther finfish price	0.01 (0.18)	0.17 (2.28)**	0.03 (0.72)	0.03 (0.7)	0.06 (1.51)
ΔHake sale Arg.	0.04 (1.42)	0.08 (2.04)**	0.01 (0.41)	0.01 (0.35)	0.009 (0.29)
ΔHarbour price	0.18 (1.31)	0.26 (1.74)*	0.15 (1.2)	0.13 (0.84)	0.06 (0.39)
ΔWholesale price	− 0.3 (− 1.59)	− 0.44 (− 2.08)**	− 0.19 (1.01)	− 0.03 (− 0.16)	0.006 (0.03)
Δ*U*[LV2*a*]					0.1 (2.28)**
z_{-1}	− 0.4 (− 4.28)***	− 0.28 (− 2.6)***	− 0.66 (− 7.24)***	− 0.63 (− 6.08)***	−0.61 (−5.78)***
Long-run coefficients (θ_j)					
Constant	0.53 (0.32)	− 0.79 (− 0.29)	0.3 (0.32)	0.59 (0.53)	0.35 (0.29)
Hake price Arg.	− 0.22 (−0.86)	− 0.04 (−0.09)	0.08 (0.52)	− 0.006 (− 0.03)	− 0.003 (− 0.02)
Hake price Nam.	0.71 (2.1)**	0.56 (0.92)	0.37 (1.79) *	0.48 (2.07)**	0.72 (2.64)***
Other finfish price	0.02 (0.18)	0.62 (1.73)*	0.05 (0.71)	0.05 (0.69)	0.11 (1.47)
Hake sale Arg.	− 0.08 (− 0.74)	0.28 (1.51)	− 0.12 (− 2.14)**	− 0.09 (− 1.34)	0.02 (0.29)
Hake sale Nam.	− 0.01 (− 0.08)	0.02 (0.11)	0.02 (0.46)	0.06 (1.22)	0.05 (1.04)
Harbour price	0.45 (1.23)	0.95 (1.39)	0.23 (1.2)	0.2 (0.82)	0.1 (0.39)
Retail price	0.25 (0.32)	0.03 (0.02)	0.21 (0.48)	− 0.05 (− 0.16)	− 0.39 (− 0.73)
Wholesale price	− 0.76 (1.51)	− 1.59 (− 1.67)*	− 0.28 (− 1.02)	− 0.18 (− 0.35)	0.01 (0.03)
U[LV2*a*]					0.16 (2.11)**
{U[LV2a_{-5}]}					*{−0.14} (−1.93)**
U[LV2*n*]					−0.04 (−0.42)
{U[LV2n_{-5}]}					*{0.17} (1.8)**

Table 4 (continued)

Estimation period	April 2004–April 2016	April 2004–December 2012	January 2006–December 2014	January 2008–April 2016	January 2008–April 2016
	A	B	C	D1	D2
Post1	0.29 (1.84)*	0.46 (1.5)	0.2 (2.23)**	0.22 (2.17)**	0.26 (2.5)***
Post2	0.03 (0.19)	0.13 (0.45)	0.12 (1.16)	0.02 (0.14)	0.04 (0.31)
Regression diagnostics					
F_{PSS}	2.57[a]	1.01	5.87***	4.95***	4.11*** *[4.14]* ***
AR(2)	1.87	2.67*	1.04	1.75	1.33
AR(12)	1.76*	1.44	1.41	2.11**	0.58
ARCH(12)	0.72	0.76	1.02	0.59	1.098
Norm. $\chi^2(2)$	13.2***	1.58	2.66	22.15***	11.47***
SBC	− 0.44	− 0.36	− 0.673	− 0.593	− 0.533 *[− 0.67]*
R^2 (adj.)	0.44	0.46	0.31	0.24	0.23
N	145	105	108	100	100

Dependent variable: *Hake price* (in ARDL model in levels), *ΔHake price* (log-differenced, in 2nd-step cointegrating regression; autoregressive parameter estimates not included (models A and B)). In parentheses are t statistics (in italics, for model D2: estimates/diagnostics if average vessel inefficiencies used with fifth lag, instead of no lag). z_{-1} error correction term (= {Hake price – [$\theta_0 + \theta_1$Hake price Arg. + …]}$_{-1}$)

AR(.), residual correlation of 2nd or 12th order (Breusch-Godfrey LM F test); *ARCH(12)*, residual autoregressive conditional heteroscedasticity of the 12th order (*F* test). *Norm.* χ^2 *(2)*, Jarque Bera residual normality χ^2 test; *SBC*, Schwarz Bayesian Criterion; *N*, sample size

*$p \leq 0.10$; **$p \leq 0.05$; ***$p \leq 0.01$ (F_{PSS} above upper critical value bounds)

[a] Inconclusive F_{PSS} statistic (bounds test of H_0 of no cointegration; Pesaran et al. 2001): within critical value bounds at 2.5% stat. significance (and less than lower critical value bound at 1% stat. significance)

Table 5 Long-run coefficients and asymmetric price transmission (retail versus upstream hake market prices: April 2004–April 2016 and rolling window)

Estimation period	April 2004–April 2016	April 2004–December 2014	January 2006–April 2016	
	E	F1	F2	TAR (2;1)
Cointegrating regression				
ΔWholesale price	0.09 (7.19)***	0.07 (5.77)***	0.07 (5.54)***	
ΔHake price Arg.	0.02 (1.57)	0.02 (2.06)**	0.01 (1.17)	
ΔHake price Nam.	0.02 (1.63)*	0.01 (0.6)	0.01 (1.05)	
z_{-1}	− 0.21 (− 5.88)***	− 0.16 (− 5.06)***	− 0.17 (− 5.63)***	
Long-run coefficients (θ_j)				
Constant	1.86 (18.1)***	1.96 (13.1)***	2.0 (15.1)***	
Wholesale price	0.42 (10.98)***	0.42 (8.1)***	0.4 (8.45)***	
Hake price Arg.	0.08 (1.64)*	0.15 (2.01)**	0.08 (1.16)	
Hake price Nam.	0.09 (1.52)	0.05 (0.59)	0.09 (1.02)	
Prior		− 0.15 (− 2.7)***	− 0.11 (− 2.32)**	
Threshold regression				
$z_{-1} < -0.034$ (19.7%)				
Constant				0.06 (3.47)*** *[4.13]****
Δz_{-1}				− 0.31 (− 2.25)** *[− 2.48]****
$z_{-1} > -0.034$ (80.3%)				
Constant				− 0.02 (− 2.8)*** *[− 3.36]****
Δz_{-1}				− 0.03 (− 0.23) *[− 0.41]*
Regression diagnostics				
F_{PSS}	3.14[a]	2.12	3.82*	
$F_{BP}(1\|0)$				28.5**
$F_{BP}(2\|1)$				11.1

Table 5 (continued)

Estimation period	April 2004–April 2016	April 2004–December 2014	January 2006–April 2016	
	E	F1	F2	TAR (2;1)
AR(2)	2.52*	2.88*	0.05	7.65***
AR(12)	2.13**	1.58	0.71	5.89***
ARCH(12)	2.36***	0.85	0.6	4.69***
Norm. $\chi^2(2)$	1.89	6.27**	2.14	58.6***
SBC	− 4.86	− 4.92	− 5.02	− 2.34
R^2 (adj.)	0.95	0.96	0.96	0.27
N	145	129	124	124

Dependent variable: *Retail price* (in ARDL model in levels), *ΔRetail price* (log-differenced, in 2nd-step cointegrating regression; autoregressive parameter estimates not included (model F1)); Δz_{-1} (in TAR, i.e. differenced error correction term from model F2). In parentheses are t statistics; in brackets/italics (TAR) are t statistics based on Newey-West heteroscedasticity and autocorrelation consistent (HAC) standard errors (Newey and West 1987). z_{-1} error correction term (= {Retail price – [$\theta_0 + \theta_1$Wholesale price + …]}$_{-1}$). $F_{BP}(k+1|k)$ sup-F test of ($k+1$ vs. k) sequentially determined thresholds (Bai and Perron 2003b)

AR(.), residual correlation of 2nd or 12th order (Breusch-Godfrey LM F test); ARCH(12), residual autoregressive conditional heteroscedasticity of the 12th order (F test); *Norm.* χ^2 *(2)*, Jarque-Bera residual normality χ^2 test; *SBC*, Schwarz Bayesian Criterion; N, sample size

*$p \leq 0.10$ (F_{PSS} above upper critical value bounds); **$p \leq 0.05$; ***$p \leq 0.01$

[a] Inconclusive F_{PSS} statistic (bounds test of H_0 of no cointegration; Pesaran et al. 2001): within critical value bounds at 10% stat. significance (and less than lower critical value bound at 5% stat. significance)

to lag order: over a grid search up to 6 months backwards on vessel inefficiencies, statistically significant parameters with reversed sign are associated with five-month lagged inefficiency scores of vessels with A-Y licences, thus implying possible delayed effects (Table 4—in italics). This issue would deserve further econometric testing, geared to account explicitly for shipment costs and delivery lags between south Atlantic finfish catches and major landing ports. Moreover, the analysis would gain insights by testing the impact of changes in productivity across fishing fleets of supplier countries on finfish product quality, and hence indirectly on output prices (Färe et al. 2015).

Consumer market and value chain transmission

None of the market stages within the Spanish value chain for fresh hake supply and consumption appeared to exercise a significant influence on prices received by Falkland frozen hake exporters at Spanish ports (Table 4: *Harbour/retail/wholesale price*). Conversely, Spanish retail prices of hake had less than proportionate long-run equilibrium changes to respective wholesale price movements (Table 5: $\theta_{\text{Wholesale price}} \cong 0.4$), with weaker responses in the short run. Seasonal demand factors, mainly related to December peaks, partly overlapped with similar seasonal import price upturns of frozen hake from Namibia, but the relevance of the latter variable for retail prices is siphoned off if an end-of-year dummy is used (Table 5: *Prior* vs. *Δhake price Nam.*). Other than that and after accounting for wholesale prices, retail prices of fresh hake are largely independent of prices at ports of frozen hake imported from Argentina and Namibia.[12] Unlike a relatively high speed-of-adjustment parameter in the Spanish import market for Falkland hake (Table 4, z_{t-1}: $\alpha_{z(t-1)} \cong 0.6$), less than one fourth of market price disequilibria from the long-run relationship in the Spanish hake market chain is removed by agents on a monthly basis (Table 5, z_{t-1}: $\alpha_{z(t-1)} \cong 0.2$; Harris 1995).

The latter result is likely to reflect higher adjustment costs, but it may also be a spurious outcome of asymmetric price adjustments in the hake value chain, as discussed in section 3. Unlike evidence from another fish market (Bluefin tuna in Japan; Nakajima et al. 2011), TAR and M-TAR models on log-differenced residuals from the first-step level equation of ARDL-SBC model F2 (Table 5), suggest no asymmetry in price adjustments around long-term equilibrium in the Spanish fresh hake market over the period 2006–2016 (results not reported for space reasons). The hypothesis of asymmetric price adjustments by retailers finds support only relative to short-run shock dynamics (Appendix 2: Eq. (8a)). Prior-month ‘shocks’ (rates of change of deviations from long-run price equilibrium in the market chain) are relatively quickly offset whenever Spanish hake retail prices fall short of this equilibrium level, relative to wholesale prices. This is captured by statistically significant parameters with a positive sign for intercept and a negative sign for slope in a TAR(2;1) model, whenever the error correction term reflects this disequilibrium (Table 5: $z_{t-1} < -0.034$). Conversely, short-run shocks in the opposite direction show less clear behavioural responses, other than a

[12] Based on Apr 2004–Apr 2016 median monthly values, Spanish retail fresh hake prices were more than twice as high as the respective domestic wholesale prices, more than three times higher than harbour prices, and nearly eight times higher than port-sale prices of frozen hake from the three south Atlantic exporters. However, these differences do not take into account product changes across, and partly within, levels of the market chain (Homans and Wilen 2005).

relatively weak reversal driven by a statistically significant but small negative intercept parameter.[13]

Conclusion

An assessment of market integration and price transmission vis-à-vis major fish producers, exporters and consumers can shed light about fishery viability and sustainability, particularly in a small, open economy. Declining dependence of Falkland fisheries from major competing producers with a quality premium over *Merluccius hubbsi* from the Islands, and/or from oligopsonistic retailers, would suggest improved scope for greater autonomy in finfish export sales and efficient markets. By contrast, strategic behaviour and adjustment costs by local retailers in consumer markets would be reflected by asymmetric price transmissions, with downward price movements followed by slower and incomplete adjustments down the chain (unlike price increases). These patterns would imply suboptimal resource allocation, with consumer prices exceeding market-clearing equilibrium price during periods of excess primary supply (AIPCE-CEP 2015).

Southern hake catches of Falkland vessels show high responsiveness to fishing effort and latent skipper skills. Unexpectedly somehow, apart from different production frontiers, vessels with A-Y licences, which allow hake as their main target, have not proved to be more efficient than other finfish vessels. Based on results from stochastic frontier models accounting for latent skipper skills, with or without dummies for fishery regime change and vessel upgrades, inefficiencies of finfish vessels have not significantly declined over time. Moreover, technical inefficiencies of hake-targeting fishing vessels seem to undergo some trade-offs relative to Falkland hake price movements at Spanish ports. With similar information on other fishing fleets, possible extensions of this analysis would benefit from testing the role of fishery production frontiers and vessel inefficiencies in major supplier countries, and implications on fish landings in consumer markets.

Despite the enduring global economic crisis and relative to main south Atlantic finfish supplier countries, international and domestic hake markets have experienced increasing integration in recent years, both between suppliers and within the value chain in Spain. Of the two major supplier countries of south Atlantic hake (Argentina and Namibia), Namibian producers appear to exercise some influence on the market, including for Falkland frozen hake sold at Spanish harbours. Limited to short-run price adjustments, this also applies to Spanish retailers vis-à-vis fresh hake sold at higher levels of the value chain. Moreover, seasonal effects substantially influence the supply and demand of hake, including increased catches during the *Illex* squid season in the Islands. However, producer and consumer markets turn out to be weakly interlinked.

The current regulatory approach to finfish licences in the Falklands finds mixed support from the econometric results on vessel efficiency and price formation. Relative to the latter, this is not surprising since Falkland fisheries have remained largely price-takers for finfish products in the main outlet market. Lack of cooperative fishery management between the Islands and Argentina further constrains potential economic

[13] To ensure sufficient numbers of observations on each side of potential thresholds (Enders 2010, p. 444), trimming parameter estimation was based on a minimum τ equal to 0.15 (Appendix 2: Eq. (10)), that is 15% from lowest or highest values.

benefits (Villasante and Sumaila 2010). Operating cost data are unavailable on a consistent basis, thus hindering a comparison across Falkland vessels and with other finfish exporters: from vessel accounts in recent years, operating costs have been around 15–30,000 UK pounds per vessel per fishing day, including days outside Falkland seawaters. However, compared with hake from Argentina and Namibia, exports of hake and other finfish from the Falklands to Spain have been more unstable in unit price and quantity terms, and, except for hake prices, no improvement is observable over time. This can act as a disincentive to plans for upgrading and replacing vessels. Yet, recent technology upgrades, such as a newly launched state-of-the-art diesel-electric longliner for Patagonian toothfish (fishingnews.co.uk/news), allow foreseeing solid prospects for continuous development of fisheries in the Falkland Islands.

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Appendix 1: Hake and squid species in Falkland waters

Oceanographic conditions highly influence fish migratory flows and other seasonal features of the biological cycle in the Patagonian Shelf. As observed for other fisheries (Guijarro et al. 2012), reproductive and migratory habits induce intra-year patterns in population dynamics. Both southern hake species (*Merluccius australis* and *Merluccius hubbsi*) are seasonal migrants, moving from inshore spawning grounds, mainly in Argentina's Exclusive Economic Zone (EEZ), to adult feeding grounds in Falkland seawaters. *M. australis* is mostly present in the western part of Falkland EEZ during the first half of the calendar year, in the austral summer and autumn, with relatively high catches in February–May. *M. hubbsi* tends to migrate a few months after, consequently starting their feeding season later (Falkland Islands Government (FIG) 2014; Portela et al. 2002).

The Patagonian shortfin squid (*Illex argentinus*) constitutes one of the most important fish resources in the Shelf. It has a life cycle of nearly 1 year with strong variation in biomass from year to year, and its distribution is limited to the area of confluence of cold and warm currents of sub-Antarctic (Falkland Current) and sub-tropical origin. Along with another local squid (*Loligo gahi*), *Illex* is among prey fishes for hakes, although the impact on stock appears to be limited since most predation mortality concerns fish of young age. The reverse also occurs, with young hake being preyed on by maturing Patagonian shortfin squids (Villasante et al. 2015). In years with no strong sea-surface temperature anomalies, the Falkland EEZ and adjoining high seas register peak concentrations of *Illex* between March and May. Squid migrations to warmer Argentine spawning grounds take place in July and August (Portela et al. 2005). At the end of the *Illex* fishing season, more frequent stormy weather conditions often hamper effective fishing, for a relatively small number of jigging vessels allowed to fish *Illex* till mid-June (Falkland Islands Government (FIG) 2014).

During the *Illex* season, vessels with G-licences, which includes *Illex* as a target species, often register the largest shares of hake catches, even if these account sometimes for less than 10% of total catches by G-licence fleet (Falkland Islands Government (FIG) 2014). The pattern of hake catches per fishing hour partly reflects these

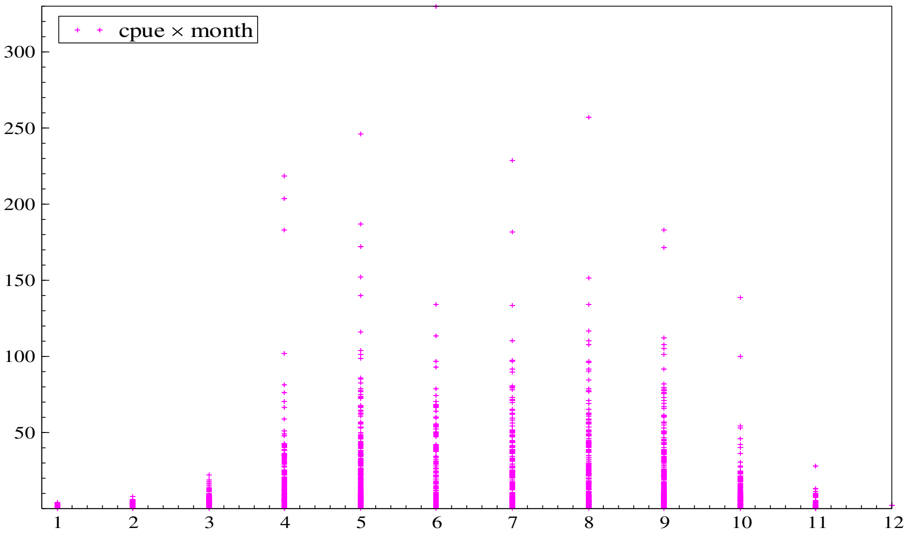

Fig. 5 CPUE (Falkland hake, January 2008–July 2017)

features of Falkland fisheries, even if a few vessels might have underreported the fishing time in months of high catches (Fig. 5: CPUE in tens of kilogrammes of hake per hour spent at sea, by month). Hake is mainly harvested in northern and western parts of the Falkland EEZ. This also applies to *Illex* and rockcod, with more dispersed distribution for the latter. Since its establishment in 1990, restricted grounds for fishing of *Loligo gahi*, which extend on the shelf edge around the Islands from east to south, have served a double purpose: keeping finfish vessels out of the *Loligo* squid fishery and avoiding incidental capture of juvenile finfish by vessels targeting *Loligo* (due to different minimum mesh sizes; Falkland Islands Government (FIG) 2014). Beyond the Falkland EEZ, a few pelagic trawler vessels are allowed to fish in South Georgia island seawaters, with icefish licences awarded on an annual—prior to 2014—and, more recently, biennial basis, according to stringent standards (Pelembe 2014).

Appendix 2: TAR models

Based on an observable regime-change signal (*threshold variable*) q_t, a TAR(m;p) model with autoregressive order p partitions strictly increasing values of a random variable into m regimes separated by $m-1$ threshold values γ_j ($j=1,\ldots, m-1$), with theoretically unbounded extremes $\gamma_0=-\infty$, $\gamma_m=\infty$. The model yields m regime-specific parameters. In particular, a TAR(2;1) is applicable to differenced residuals $\Delta\varepsilon_t$, where ε_{t-1} represents the error correction term from a cointegrating regression (Table 5: z_{t-1}). In general notation as TAR(m;1), this can be expressed as Eq. (8a) (testing APT in short-run readjustments from prior rates of change of deviations from equilibrium) or Eq. (8b) (testing APT in magnitude and strength of response to these deviations, that is cointegration with threshold non-linearity). The variance of the random error η_t may vary across regimes and $1_j(q_t, \gamma)$ is a Heaviside indicator function

(= 1 if $\gamma_j < q_t < \gamma_{j+1}$; = 0 otherwise). Thresholds and parameter estimates are global minimisers of the objective function Eq. (9), where S_γ is the sum of squared residuals (η_t^2) in the partitioned sample. In this equation, the ratios $\lambda_{[j]}$ (= γ_j/γ) are such that each threshold value is distinct and bounded away from extreme values of q_t.

$$\Delta\varepsilon_t = \Sigma_{j=1,..,m-1} 1_j(q_t, \gamma)\cdot\left[\varphi_{0j} + \varphi_{1j}\Delta\varepsilon_{t-1}\right] + \eta_t \quad \left(\eta_t \sim N\left[0, \sigma_{\eta|j}{}^2\right]\right) \tag{8a}$$

$$\Delta\varepsilon_t = \Sigma_{j=1,..,m-1} 1_j(q_t, \gamma)\cdot\left[\alpha_j\varepsilon_{t-1}\right] + \varphi_1\Delta\varepsilon_{t-1} + \eta_t \quad \left(\eta_t \sim N\left[0, \sigma_{\eta|j}{}^2\right]\right) \tag{8b}$$

$$(\gamma_1, \gamma_2, \dots, \gamma_{m-1}) = \text{argmin}_{(\lambda[1],\lambda[2],\dots,\lambda[m-1])} S_\gamma(\gamma_1, \gamma_2, \dots, \gamma_{m-1}) \tag{9}$$

$$\Lambda_\tau = \left\{(\lambda_1, \lambda_2, \dots, \lambda_{m-1}); \left|\lambda_{j+1} - \lambda_j\right| \geq \tau, \lambda_1 \geq \tau, \lambda_{m-1} \leq 1 - \tau\right\} \tag{10}$$

Bai and Perron (2003a/b) propose a dynamic programming algorithm solution of Eq. (9), subject to asymptotic consistency rules defined in Eq. (10) (where a trimming parameter τ is the ratio of a minimum segment length h to the range of q_t, i.e. $\tau = h/\gamma$). Relative to an analogous treatment with breakpoints, which replaces γ_j with T_j and γ with T, see Bai And Perron (1998, 2003a). Threshold regression and breakpoint testing are fundamentally equivalent: in the latter, by permuting the observation index, time is the threshold variable (IHS 2015, p. 428; Tsay 1989).

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