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Fewer Fish for Higher Profits? Price Response and Economic Incentives in Global Tuna Fisheries Management

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Abstract This paper evaluates industry-wide economic incentives arising from changes in product prices in an industry exploiting a common renewable resource (tropical tunas) that is regulated via output limits. Changes in prices alter economic incentives by affecting revenues, profits, conservation, and nonmarket public benefits. Economic incentives in industries exploiting common resources have been examined from multiple angles. However, industry level variation in market prices arising from changes in public regulation has not been explored. We analyse the impact on economic incentives due to changes in output limits and market prices through estimation of ex-vessel price and scale flexibilities for imported skipjack and yellowfin in Thailand's cannery market. The unitary scale flexibility, estimated

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from the General Synthetic Inverse Demand Systems, indicates no loss in revenue and even potential profit increases resulting from lower harvest levels that could arise from lower catch limits. However, for a revenue neutral or positive outcome to be achieved, the three inter-governmental tuna Regional Fisheries Management Organizations, which manage the majority of the yellowfin and skipjack tuna in the Pacific and Indian Oceans, would have to coordinate multilaterally to set the catch limits for both species.

1 Introduction

Identifying the correct set of incentives for the efficient conservation and management of common renewable resources is one of most significant challenges faced by policy makers today. Since Gordon (1954), the economic literature has focused on incomplete property rights as the primary cause of resource overexploitation. Given this perspective, it is not surprising that most policy solutions use privatization or Pigovian taxes to realign individual-level incentives with social objectives (Wilen 2000; Grafton et al. 2006). Most of the literature also depends on simplifying assumptions, such as a single sector that is closed to trade or a single autarkic economy. However, there is little research on the effects of regulation on supply and the subsequent impact upon prices, revenues, profits, and, ultimately, industry-wide economic incentives. A second missing element is the effect of globalization on regulatory effectiveness and related industry-wide adjustments. With a better understanding of these two issues, it should be possible to estimate the full costs and benefits of regulatory actions, even for international resources such as tropical tunas, which are harvested globally by fleets from many nations and traded all over the world.

In this paper we measure an example of a broad shift in incentives and show that international, industry-wide response to regulations can have profound effects on the effectiveness of common renewable resource management. Unintended consequences of management can reinforce regulation, but are often counterproductive given policy goals. Furthermore, industry-wide effects of regulation, such as changes in product prices, can alter rates of exploitation regardless of how property rights are structured. This is the reasoning behind the use of Pigovian taxes in common pool resource management, but attention has yet to be given to price responses arising from other channels; notably through changes in industry-wide output limits. For instance, by limiting an input factor, regulators can temporarily increase costs of production until a substitute for the input is found. On the other hand, limits on the extraction of one resource often lead to substitution, which undermines the economic benefit of the regulation by keeping prices low and can result in the overexploitation of the substitute. This effect is amplified when products from the regulated industry enter into regional or global markets because market price responses may diminish due to larger volumes of trade and increased substitution possibilities.

Unintended economic effects of regulation can also have political impacts. Changes in supply and related price effects can undermine or reinforce incentives to comply with all types of management, including property-based systems. For example, any locally restricted input usage that lowers total output increases incentives for noncompliance if total revenues rise proportionately less than the output decrease. The reverse also holds if revenues rise proportionately more than the output decrease. High profitability also tends to heighten political

pressure to weaken restrictive conservation measures. In fisheries, this can drive catch limits well above scientifically recommended levels, dissipating economic and environmental benefits over time (Webster 2015). This problem tends to be worse in international settings, where the perceived distributional effects of regulations often prevent the negotiation and implementation of effective management measures, whether through stiffer command-and-control regulations or market-based regulatory instruments (Barkin and Shambaugh 1999). Moreover, when markets for common renewable resources are global, management may not be effective unless efforts are coordinated at scales that match primary products' market distribution.

In order to develop methods to quantify the industry-wide changes in incentives associated with different regulatory options, we estimate price and scale flexibilities of the inverse demand system for Thailand's tuna cannery market, which is the largest in the world and exerts global price leadership, importing more than half of global catches of skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*). The unitary scale flexibility we estimated indicates no loss in revenues and even potential profit increases stemming from lower overall catch limits, i.e., a decrease in landings of both species at the same time is accompanied by the same proportionate increase in price. These mutually beneficial catch limits for both yellowfin and skipjack could be implemented through international regulation, but this would require coordination among the three inter-governmental tuna Regional Fisheries Management Organizations[1] (tRFMOs) that manage these fisheries in the Pacific and Indian Oceans. Such regionally coordinated, multi-species regulation faces a roving bandit problem (Berkes et al. 2006), since tuna fleets can move between regions, and a weakest link problem, since our results show that reductions of quantity supplied for only one species would not have the desired price effects due to species substitution in the Bangkok market.

The paper is organized as follows. Section 2 reviews the literature on economic incentives for fisheries to show how our focus on catch limits, supply, prices, and incentives contributes to the literature; it also sets the stage for the empirical analysis. Section 3 surveys the demand systems and market delineation literature to justify separate estimations of the canned tuna value chains and then presents the detailed demand model. Section 4 provides the empirical results. Section 5 discusses the elasticity and flexibility coefficients found in the empirical literature and their consequences for fisheries management and Section 6 gives some concluding remarks.

2 Background: Fisheries Incentives and Tunas

Work dealing with incentives in the fisheries literature focuses primarily on individual and group property rights and their impact upon harvesters (see Segerson and Zhou 2014 for a review). Recent literature has also considered what regulations can be used to align harvester incentives with management objectives across seasons, across multiple and higher valued species, or across product quality and form (see Smith 2012 for a review)[2]. Another strand

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[1] There are five tRFMOs, including Intra-American Tropical Tuna Commission (IATTC), International Commission for Conservation of Atlantic Tuna (ICCAT), Western and Central Pacific Fisheries Commission (WCPFC), Indian Ocean Tuna Commission (IOTC) and Commission for Conservation of Southern Bluefin Tuna (CCSBT). Except CCSBT is solely managing global TAC of southern bluefin tuna, the other four tRFMOs all define their conservation measure by managing the fishing effort of large scale tuna purse-seine fleet targeting skipjack and yellowfin tuna in each of their region, instead of global catch limits.

[2] Harvester incentives also arise out of asymmetric information in response to regulations and other policies (Vestergaard 2010).

of literature examines incentive structures and regulatory issues arising in internationally managed fisheries that require self-enforcing multilateral cooperation (see Finus and Schneider 2012 for a review). The literature also examines the impact upon incentives from spatial externalities (Ibid.) and discusses the effect of international trade on incentives in open-access fisheries (see Copeland and Taylor 2009 for a review). One source of incentives missing from the literature is the impact of changes in catch limits on prices and revenues upon industry-wide incentives, especially in globally or regionally integrated seafood markets; this is a significant gap given that seafood is the most highly traded food commodity in international markets integrated by prices and commodity flows.

Tuna species represent a resource management challenge due to their extensive geographic distribution and migratory nature, but also because of their global market demand and the diversity of fisheries that exploit the resource. Global catches of skipjack and yellowfin tuna in 2012 were 2.5 million mt and 1.2 million mt, respectively (Food and Agriculture Organization of the United Nations 2012). More than 80 % of skipjack and almost half of yellowfin tuna catches are landed by large-scale tuna purse-seiners and delivered to canneries. Large bigeye and yellowfin destined for the sashimi market are caught in the tuna longline fishery.

Since the 1990s, Thailand has been the world's largest producer of "light" canned tuna, primarily composed of skipjack tuna. Thailand imports more than half of the global imports of frozen skipjack and yellowfin destined for canneries, and its processing companies increasingly dominate global production and trade. Its annual imports have doubled within the past decade. Monthly imports of yellowfin tuna are less than 10,000 mt, but imports of skipjack are five times greater than yellowfin tuna, and reached 62,000 mt in February 2010 (Fig. 1). The right vertical axis of Fig. 1 shows total imports, which is stacked by imports of skipjack tuna in red bars on top of the imports of yellowfin tuna in blue bars. The average import price of frozen yellowfin tuna, fetching 1,500 US$/mt in 2010–2011, is about US$300 higher than the average import price of frozen skipjack. Thailand's imports of both species nearly doubled during the period 2001–2009 from 400,000 mt to 760,000 mt imported yearly to supply the fast-growing canning capacity. The top three importing countries of light canned tuna from Thailand in both quantity and value are the United States, France, and the United Kingdom, which purchase over one-third of world imports of canned tuna. About 70 % of U.S. canned tuna is imported from Thailand. Taiwan is the major supplier of fish to canneries
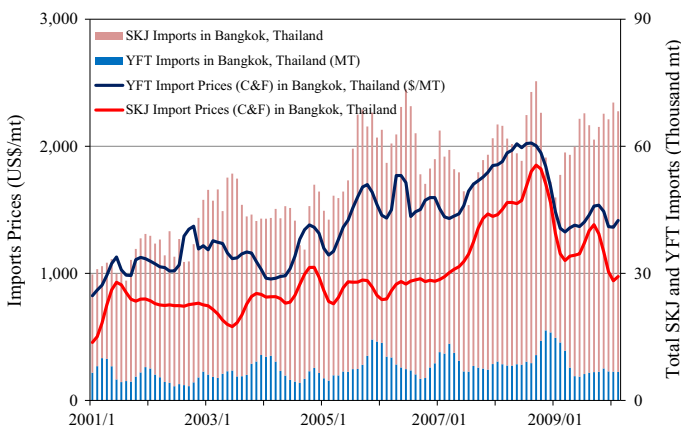

Fig. 1 Monthly average import prices and total imports of frozen skipjack and yellowfin tuna for canning in Bangkok, Thailand (*Source: Thailand Customs*)

(20 %), followed by the USA (19 %), and South Korea (17 %). Japan, France and various other purse-seine fleet flag states from all over the world also supply smaller amounts of tuna to the canneries.

The tuna-Regional Fisheries Management Organizations (tRFMOs) have utilized different approaches and practices to curb overexploitation, but overcapacity in the fishery persists in driving overexploitation and remains a problem (Joseph et al. 2010). Conservation efforts are hampered by the misalignment of economic incentives with conservation objectives and allocation conflicts among fishing nations with different target species and gear types. Miyake et al. (2010) reviews tuna fisheries, tuna markets, and tRFMOs.

Public regulation largely remains focused at the individual tRFMO level, but due to the global integration of tuna markets by both price and commodity flows (Jeon et al. 2008; Jiménez-Toribio et al. 2010), there are unexploited avenues for conservation arising through these globally integrated markets. Specifically, lowering formal or informal catch limits at the regional level might impact prices globally, altering incentives to fish. Setting formal and informal catch limits tends to be less contentious than most other conservation and management measures given the widely accepted focal point (and even international norm) of maximum sustainable yield (MSY). Moreover, the distributional impacts that impede regulatory measures affect virtually all parties, but in ways that are often unknown and uncertain. This makes it difficult to identify or implement Pareto improving management options. However, their joint concern regarding the prevalence of freeriding nonmembers has generated considerable political will and greatly improved regional coordination among the tRFMOs.

For all fisheries, the impact of regulation on prices and revenues depends in part on the shape of the yield curve when formal or informal catch limits are set. However, cannery grade skipjack and yellowfin tuna populations exhibit a comparatively stretched flat area at the top of their yield-effort curves, which means that they can be exploited heavily for long periods of time before biomass begins to decline below levels that support MSY. Therefore, for these fisheries, impact is primarily determined by the nature of the ex-vessel product price response to changes in catch levels, which is in turn set by the aggregate supply in the market where ex-vessel product prices form. Depending on the responsiveness of product demand to declines in catch limits, catch reductions—driven by conservation measures jointly set by tRFMOs—can lead to prices that increase proportionately more than the fall in quantity supplied, leading to revenue increases. This statement is true under specific assumptions of effective markets where equilibrium prices and quantities can adjust in the long term. The tuna market for canneries at the global level has proved to be competitive enough to allow for such adjustments (Jeon et al. 2008; Jiménez-Toribio et al. 2010).

Reduced fishing can not only increase revenues, but also lower costs and boost profits. Cost reductions can stem from both the decrease of fishing effort and associated input costs at lower catch levels and from the marginal stock effect as lower catch limits rebuild resource stocks, lowering search and fishing costs (Clark 1990). Should prices rise proportionately more than quantities decline, the increased revenues can finance buybacks or side payments in both national and international fisheries that reduce participation. In short, conservation, in circumstances when reduced catch limits result in price gains that outpace declines in quantity, can lower costs, boost economic rents, and generate incentives to comply with management measures, conservation, and cooperation among tRFMOs.

Tighter catch limits can also negatively impact consumer benefits, at least in the short run until stocks rebuild. Changes in prices do not always impact economic welfare to the extent that they are pecuniary rather than technological externalities. For example, part of the increase in producer benefits with a higher price and lower quantity can come through

a transfer of consumer benefits with no change in overall welfare. Higher prices can also adversely impact food security in low-income countries, which unfortunately could be subsumed under pecuniary externalities. Even when consumer benefits from direct use values decline due to a rise in price and fall in quantity, consumers can gain through increased non-market values, such as indirect use value and existence value, when larger resource stocks provide more public benefits. In short, the consumer picture is complex and falls outside of our emphasis on economic incentives facing industry, regulators, states, and conservation groups from civil society. However, to the extent that the inverse demand curve estimated in this paper is an equilibrium demand curve, the welfare measures capture both consumer and producer surplus (Just et al. 2004).

Estimated global tuna price flexibility can also provide a comprehensive method for evaluating the economic tradeoffs between two key fisheries: the tuna purse-seine fishery that targets skipjack and yellowfin tuna for canning and the tuna longline fishery that targets sashimi-quality yellowfin and bigeye tuna for direct consumption. Since the majority of juvenile yellowfin and bigeye tunas[3] are caught together with skipjack tuna destined for the canned tuna market in the purse seine fisheries, both juvenile yellowfin and bigeye tuna are caught at sizes too small to take full advantage of their individual growth and the higher price obtained for large fish in the sashimi market. Reducing skipjack harvests can provide an opportunity for sustainable production of sashimi-grade adult yellowfin and bigeye tuna (i.e. conservation of the resource versus profitability of alternative fisheries) (Sun et al. 2010).

3 Methods: A General Synthetic Inverse Demand System Approach

Evaluating economic incentives of any catch limits requires calculating the product price responsiveness, which in turn requires specifying a demand system. To model a demand system, a sequential choice of binary options has to be made before reaching a satisfactory model specification. The demand function can either be linear or logarithmic, ordinary or inverse, final or derived, Marshallian or Hicksian, static or dynamic, detailed or aggregated, etc. (Eales et al. 1997).

Previous estimates of price flexibilities for cannery produced tuna (the change in demand price when there is a 1 % change in the quantity supplied of tuna for cannery based on the inverse demand for cannery-grade tuna landings) have largely been ad hoc, estimated for single species, and derived from the price elasticity of tuna can final products (King 1987; Owen and Troedson 1994; Campbell 1998; Sun and Hsieh 2000; Owen 2001). Bertignac et al. (2000) utilized the derived demand elasticity provided by Campbell (1998) to obtain estimates of the price elasticity of demand for tuna harvested in the Western Central Pacific Ocean. Bertignac et al. estimates were derived from price elasticities of the US market demand for canned tuna, provided by King (1987) and Owen and Troedson (1994), instead of directly estimating the market demand for tuna raw material for canning.

Estimates of price flexibility would be biased if they are derived from the reciprocal of the direct price elasticity, since it could only serve as an estimate of the lower bound of the flexibility (Houck 1965). Additionally, the low flexibility values shown in Table 1 would suggest that without a systems approach, consumption substitution possibilities among

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[3] Bigeye tunas in all tRFMOs are all overfished and subject to growth overfishing because bigeye tunas are longer lived and slower growing than skipjack tuna (Miyake et al. 2010) and majority of juvenile bigeye and yellowfin tunas are caught along with skipjack tunas by purse-seine vessels when setting on floating objects and processed as the lower value cannery quality product.

Table 1 Estimated price elasticity and flexibility of demand for cannery-grade tuna landings in the literature

Study	Model (market)	Price elasticity or flexibility (in absolute value)	
Sun and Hsieh (2000)	Price transfer function (Thailand)	Frozen skipjack tuna	Price flexibility 0.05–0.55
Bertignac et al.* (2000)	Linear demand (FFA country)	Purse-seine fleet	Price elasticity 1.55 (derived price flexibility 0.65)
Owen (2001)	Linear demand (Thailand)	Skipjack tuna Own-price coefficient	0.000041 (world supply)
			0.00096 (FFA supply)

* Based on Campbell (1998)

different tuna species are being excluded, the estimates of price flexibility could be biased, and estimates would be less efficient (Wessells and Wilen 1994; Chiang et al. 2001).

The demand system itself is subject to several analyst's *ex-ante* decisions on appropriate market delineation (the relevant market spatial and sectorial boundaries). A number of recent studies have shown the strong globalization of tuna markets (Jeon et al. 2008; Jiménez-Toribio et al. 2010) and two separate market chains: purse-seine/cannery-grade and long-line/sashimi-grade tuna (Miyake et al. 2010). Each of these two distinct markets is highly integrated at the worldwide level across locations and species, making any regional change in catches important for the entire industry. The concentration of processors and traders is high in the cannery-grade frozen skipjack and yellowfin tuna, and information is rapidly transmitted from one location to another, with a clearly identified leading market at the worldwide level—Thailand (Jiménez-Toribio et al. 2010).

Using Granger causality tests, Sun and Hsieh (2000) showed that frozen skipjack tuna caught by Taiwanese purse-seiners and exported to Thailand statistically determined the ex-vessel market prices between 1993 and 1996. A monthly time-series transfer function model of Taiwanese price was specified, and the resulting estimates of the price flexibility reach -0.55 when landings are high during the mass production season from April to May, which means ex-vessel price would drop 0.55 % if landings imported from Taiwan increase 1 %. The demand is less flexible in price while landings are low during October to December. However, the data is not sufficiently comprehensive to evaluate the price response to the imports from all sources. Other authors utilized cointegration bivariate and multivariate tests through an error-correction model to show that prices of frozen tuna for canning co-moved in the long-run (Jeon et al. 2008), that the law of one price holds between yellowfin and skipjack, and that Bangkok was clearly a market leader (weak exogeneity) (Jeon et al. 2008; Jiménez-Toribio et al. 2010). However, none of the past studies have directly measured the responsiveness of prices to changes in the global supply of cannery-grade tuna and its substitution within the canning industry.

We estimate a General Synthetic Inverse Demand Systems (GSIDS) (Brown et al. 1995) that has been used to compare to the substitution of sashimi-grade tuna in the Japanese market (Chiang et al. 2001). This family of demand systems allows for several flexible specifications that give a more robust estimation than other demand system models (Laitinen and Theil 1979; Barten and Bettendorf 1989). The estimates of own and cross-quantity demand, price flexibility, and scale flexibility can be used to examine the impact of global quota management controls and other supply shifters.

In a study of the price formation of fish, Barten and Bettendorf (1989) first developed a Hicksian inverse demand model, the Rotterdam inverse demand system (RIDS), using the direct utility function and the Wold-Hotelling identity. Barten (1993) compared the RIDS and an Almost Ideal Inverse Demand System (AIIDS), along with two mixed models - one with Rotterdam-type price effects and AIIDS-type income effects and the other with AIIDS-type price effects and Rotterdam-type income effects. Barten (1993) proposed a synthetic direct model that combines the features of the latter four models and allows non-nested hypothesis testing among models. Brown et al. (1995) specified a family of general synthetic inverse demand systems (GSIDS), which includes two flexible specifications: the RIDS and Almost Ideal Inverse Demand System (AIIDS) on the one hand (Barten and Bettendorf 1989), and the inverse demand system proposed by Eales et al. (1997) on the other hand. The GSIDS can be written as:

$$w_{it} \, d \ln \pi_{it} = (h_i - d_1 \, w_{it}) \, d \ln Q + \Sigma_j \left(h_{ij} - d_2 \, w_{it} \left(\delta_{ij} - w_{jt} \right) \right) \, d \ln q_{jt} \qquad (1)$$

where subscript t represents time; π_{it} is the normalized price ($\pi_{it} = p_{it}/m_t$) of good i; with p_{it} and m_t being the price of good i and total expenditure at time t, respectively; q_{it} is the quantity of good i at time t; $w_{it} = q_{it} \pi_{it}$ is the budget share of q_{it}; $d \ln \pi_{it} = log(\pi_{it}/\pi_{it-1})$; $d \ln q_{it} = log(q_{it}/q_{it-1})$; where δ_{ij} is defined as a dummy variable to determine the cross-product flexibility effect through the impact of jth good on ith good.If it is for evaluating the own quantity then $\delta_{ij} = 1$ if $i = j$, else for cross-quantity when i $\neq$ j then $\delta_{ij} = 0$; and $d \ln Q = \Sigma_j w_{jt} \, d \ln q_{jt}$ is the Divisia volume index. The scale flexibility is calculated as:[4]

$$f_i = h_i/w_i - d_1 \qquad (2)$$

Scale flexibilities in inverse demand systems describe how marginal valuations change with proportional expansions in the quantity of the whole consumption bundle. Such effects clearly are related to income elasticities in direct demand systems. However, the link between scale flexibilities and income elasticities is tight only if preferences are homothetic, a situation where neither measure is interesting, or if all elasticities of substitution are unitary (Park and Thurman 1999).

The compensated cross-price flexibility is calculated as:[5]

$$f_{ij}^* = h_{ij}/w_i - d_2 \left(\delta_{ij} - w_j \right) \qquad (3)$$

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[4] The scale flexibility is analogous to the total expenditure elasticity of direct demand (Anderson 1980). It indicates how much price i changes in response to a proportionate increase in all commodities, i.e. it indicates how much a price changes when increasing the scale of the commodity vector along a ray originating from the origin through a commodity vector (in this case the new commodity mix resulting from a quantity change). Scale flexibilities are less than -1 for necessities and greater than -1 for luxuries. If scale flexibilities are -1 as unity then increase in landings of both species at the same time is accompanied by the same proportionate increase in price.

[5] Anderson (1980) shows that the total change in prices for a change in quantity is comprised of a scale effect (a movement from an initial indifference curve to a new indifference curve measured on a ray from the origin through the new commodity mix) and a price effect reflecting a change in commodity mix in consumption (moving along the initial indifference curve from the initial to new commodity mix). Compensated flexibilities hold utility constant (keeping a consumer on the same indifference curve) thereby removing the scale effect, whereas uncompensated flexibilities allow both utility or scale and prices to change. Compensated inverse demand functions give the levels of normalized prices that induce consumers to choose a consumption bundle that is along the ray passing through the new commodity mix bundle and that gives a constant utility level.

Table 2 Monthly statistics of the cannery-grade tuna market in Bangkok

	Mean	SD	Minimum	Maximum
Quantity sold (metric tons; mt)				
Frozen skipjack	43,994	13,033	19,273	78,594
Frozen yellowfin tuna	7736	3363	2532	21,216
Average auction price (US$/mt)				
Frozen skipjack	994	305	472	1,910
Frozen yellowfin tuna	1388	316	755	2205
Revenue share				
Frozen skipjack	80.3%	78.9%	82.6%	76.2%
Frozen yellowfin tuna	19.7%	21.1%	17.4%	23.8%
Total	100.0%	100.0%	100.0%	100.0%

Source: Thailand Customs

For simplicity, subscript t is deleted hereafter. The above inverse-demand system satisfies $\sum_i h_i = -1 + d_1$ and $\sum_i h_{ij} = 0$ (adding-up)[6], $\sum_j h_{ij} = 0$ (homogeneity), and $h_{ij} = h_{ji}$ (Antonelli symmetry). The adding-up condition $\sum_i h_i = \sum_i w_i f_i = -1$ is based on the reference quantity vector or the reference quantity vector has a scale factor $k = 1$ (Anderson and Blundell 1983).

Other models and their flexibilities are obtained by restricting d_l and d_2 appropriately: (1) $d_l = 0$, $d_2 = 0$ for the Rotterdam Inverse Demand System (RIDS) model; (2) $d_l = 1$, $d_2 = 0$ for the Laitinen–Theil (1979) model, known as Inverse Census Bureau of Statistics (ICBS) Model; (3) $d_l = 1$, $d_2 = 1$ for the Almost Ideal Inverse Demand System model (AIIDS); and (4), $d_l = 0$, $d_2 = 1$ for the RAIIDS model with RIDS scale effects and AIIDS quantity effects, known as Inverse National Bureau of Research (INBR).

The GSIDS model was estimated using full information maximum likelihood estimation and it is preferred over iterative seemingly unrelated regressions when cross equation restrictions are imposed, and estimation requires dropping one equation from the estimation to avoid singularity (Greene 2002). The above restrictions provide the basis for the likelihood ratio tests used to compare models and develop a final specification (Barten 1993).

4 Results: Inverse Demand Analysis of the Bangkok Market

The price response analysis of cannery-grade frozen skipjack and yellowfin tuna markets is based on Thailand monthly import data collected from the Thai National Customs[7] between January 2001 and February 2010 (Table 2). Because the natural logarithms of import quantities and prices of both skipjack and yellowfin tuna were found to be non-stationary for all series in Table 3, first differences were taken to specify the inverse demand system. The system-wide analogue to the Wu–Hausman test was performed and the null hypothesis of landings, treated as exogenous variables in the IDS, was not rejected with $\chi^2_{df=2}$ of 4.2385 (p value = 0.12). In testing for exogeneity in prices, the null hypothesis was rejected with

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[6] Note that $\sum_i \pi_i q_i = 1$; therefore, $\sum_i (q_i d\pi_i + \pi_i dq_i) = 0$, or $\sum_i (\pi_i q_i (d\pi_i/\pi_i) + x_i \pi_i (dq_i/q_i)) = 0$, or $\sum_i w_i d \ln q_i = -\sum_i w_i d \ln \pi_i$.

[7] http://www.customs.go.th/wps/wcm/jsp/home/index.jsp.

Table 3 Augmented Dickey–Fuller test statistics	Null hypothesis: unit root of variable in natural logarithm	t statistic	Prob.*
	Frozen skipjack tuna price	−1.708916	0.4251
* MacKinnon (1996) one-sided p values with lag length = 7 (Automatic-based on AIC, maxlag = 12)	Frozen yellowfin tuna price	−2.009382	0.2825
	Frozen skipjack tuna quantity	−0.622297	0.8615
	Frozen yellowfin tuna quantity	−1.723449	0.4164

Table 4 Maximum likelihood test statistics for Bangkok cannery market

System	d_1	d_2	Log likelihood value (LLV)	Log likelihood ratio test[a]
Synthetic	0.966** (0.115)	0.039 (0.122)	291.072	
RIDS	0	0	256.292	−69.560*** (2)
Laitinen-Theil (CBS)	1	0	290.973	−0.198 (2)
AIIDS	1	1	265.715	−50.714*** (2)
RAIIDS (NBR)	0	1	246.413	−89.318*** (2)
Free d_1, zero d_2	0.966*** (0.114)	0	291.019	−0.106 (1)
Free d_2, zero d_1	0	0.041 (0.152)	263.781	−54.582*** (1)

Numbers in parentheses are standard errors of parameter estimates and *, ** and *** indicate statistically different from zero at 10, 5 and 1 % level, respectively
[a] − 2*(LLV of each model—LLV for the synthetic model)
[b] Numbers in parentheses are standard errors of parameter estimates

$\chi^2_{df=2}$ of 4.9801 (p value = 0.0829). Therefore, the specification of an inverse demand system is valid and a set of 7 synthetic models and restricted versions of IDS were estimated. Table 4 shows the logarithmic likelihood values (LLV) for each of the models. Based on the likelihood ratio test, only Laitinen–Theil (ICBS) and the synthetic IDS with free d_1 and zero d_2 models are not significantly different than the synthetic model. The estimate of d_1 for synthetic model with free d_1 and zero d_2 is equal to 0.966.

The synthetic inverse demand system satisfies the adding-up and homogeneity conditions, but the symmetry condition cannot be imposed and the negativity condition cannot be controlled (Barten 1993). Laitinen–Theil (ICBS) is not significantly different than the synthetic inverse demand system vis-à-vis goodness of fit performance. Further comparison of the parameter estimates of scale and price flexibilities across the synthetic and the Laitinen–Theil (ICBS) models also shows no substantial differences in the estimated demand responses. The Laitinen–Theil (ICBS) model is identified as the preferable appropriate model since it is not constrained to the limitation of the synthetic inverse demand system.

The corresponding Laitinen–Theil (ICBS) estimated inverse demand scale, own-quantity, and uncompensated flexibilities are reported in Table 5. The statistically significant import price scale flexibilities for frozen skipjack and yellowfin tuna are −0.995 and −1.021. Based on the t-statistics with the standard errors of the estimated coefficients indicated in the parentheses underneath the corresponding coefficients, neither of the coefficients is statistically different from 1. These two coefficients imply that both prices will increase (decrease) by

Table 5 Scale flexibility and uncompensated own- and cross-quantity flexibility for Bangkok cannery market

| | Scale flexibility | Uncompensated own- and cross-quantity flexibility | |
		Frozen skipjack	Frozen yellowfin
Frozen skipjack	−0.995*** (0.009)	−0.797*** (0.009)	−0.198*** (0.006)
Frozen yellowfin	−1.021*** (0.036)	−0.801*** (0.097)	−0.220*** (0.029)

Numbers in parentheses are standard errors of parameter estimates

*, ** and *** indicate statistically different from zero at 10, 5 and 1 % level, respectively

1 % if total imports decrease (increase) by 1 %, and consequently that revenues will remain constant for different catch levels.

As shown in Table 5, the statistically significant uncompensated own-quantity flexibilities of demand for frozen skipjack and yellowfin are estimated at −0.797 and −0.220, respectively, and both are significantly less than unity in absolute value. This means that reducing catch levels for a single species alone, especially for yellowfin, would not compensate for the revenue loss caused by lower catches.

Using weak exogeneity tests in a Vector Error Correction Model, Jiménez-Toribio et al. (2010) showed that the yellowfin price was the leader in Bangkok, but due to the larger budget share of skipjack (79 % on average) over yellowfin (21 % on average) in this market, the skipjack price is more responsive to its own quantity than yellowfin. In other words, even though yellowfin could be first targeted by purse-seiners because of their higher market value, our results show that catch changes for this species would not have the same market impact in terms of price levels as changes in skipjack catches.

All prices of all goods are inflexible in their own consumption. The corresponding price elasticities of ex-vessel demand are most likely elastic, since the reciprocal of the price flexibility values for skipjack and yellowfin are −1.25 and −4.54, respectively. Since the reciprocal of the price flexibility forms the lower limit, in absolute terms, of the price elasticity (Houck 1965), the difference of the true price elasticity from the flexibility reciprocal depends on the entire matrix characterized by the substitution and complementarity of price flexibilities with other commodities (Huang 1994; Eales 1996).

Depending on the responsiveness of prices to declines in quantities, individual reductions in either the skipjack or yellowfin tuna catches that favor conservation without a change in the other species' catch level can lead to prices that increase proportionally less than the fall in quantity, and revenue decreases then follow. As a result of substitution possibilities between the two species, the other fishery may even benefit from the shortage in the first one by maintaining its own catch level. However, if both skipjack and yellowfin tuna catches are simultaneously reduced, the unitary scale elasticity indicates that revenue stays the same but with an increase in profit, since costs can fall with reduced fishing. Moreover, gains in non-market benefits extend to ecosystem and biodiversity impacts arising from reduced skipjack and yellowfin tuna fishing such as the reduction in bycatch associated with skipjack catch on floating objects purse seine sets, such as oceanic sharks (Dagorn et al. 2012).

5 Discussion

This study provides the first comprehensive view of a global ex-vessel market for canned tuna by estimating the price flexibilities of demand for frozen tropical tuna for canneries in

Bangkok, the global price leader for light meat canned tuna (Sun 1999). The estimated long-run scale flexibilities of demand for skipjack and yellowfin tuna are very close to unity and not significantly different from one. Similar values have been found in other studies through the use of inverse demand models applied to another global seafood market, i.e. the whitefish market (Asche and Zhang 2013). These authors found that own-quantity coefficients may vary substantially after structural changes such as the massive introduction of a farmed species like tilapia, but that scale coefficients were rather stable and close to unity at the overall group level for major and well-established fish species. Similarly, a 1 % decrease of total supply of tuna, following a reduced catch limit (e.g. caused by an environmental event or stricter conservation measures), would have the same proportional effect upon prices in the cannery market in Bangkok and revenues would remain constant.

The yellowfin price flexibility, however, indicates strong own-quantity price inflexibility and hence revenue losses with lower TACs if acting on yellowfin alone. The skipjack price flexibility also indicates price inflexibility, although it is not far from unity, suggesting that the opportunity cost of foregone skipjack revenues due to the price effect is small if both of the species are not simultaneously and proportionally managed. However, the marginal change clearly implies important variations, since it is measured using a logarithmic scale. Essentially, the unitary scale effect implies no revenue loss if the catch limits for both species could be simultaneously reduced to more efficient levels. Simultaneous catch limit regulation is thus superior to unitary catch limit regulation, because under the latter there is a revenue loss for suppliers, particularly those targeting yellowfin tuna.

Increased non-market benefits from a reduction in catch, i.e. increased private provision of public juvenile bigeye tuna for the longline fishery to target, could in principle even make up for the decline in skipjack revenue in terms of total economic value if both the global skipjack and yellowfin's catch limits are reduced. Singular skipjack regulation could create positive incentives for regulators, but negative individual fisher incentives due to the public benefits associated with increased provision of the public good of the multispecies fishery accompanying catch limits reduction.[8]

Our results challenge most previous studies that estimated elasticity and flexibility coefficients for tuna (Table 1). Many direct or indirect (converted from elasticity coefficients) estimates of flexibility values find low flexibilities in the price of tuna products (Bertignac et al. 2000; Sun and Hsieh 2000; Owen 2001). Beyond the variety of functional forms and specifications of models, we consider that both the stage of the value chains (final or derived demand) and, most of all, the scope and extent of the demand systems play a central role in the resulting estimations (Stigler and Sherwin 1985). Thorough attention paid to market delineation studies in the first section allowed identification of the world-wide scale as the only relevant level of analysis for tuna markets, which are divided in two distinct value chains that include various tuna species (Sun and Hsu 1998; Chiang et al. 2001; Jeon et al. 2008; Jiménez-Toribio et al. 2010). The price response of tuna markets to any supply shock (such as a change in catch limits) can only be observed at this level, justifying coordinated management measures by all tRFMOs.

The evolution of skipjack prices in 1998–2000 illustrates what could be the market response if a few major fleets jointly decided to reduce their catches. By mid-1998, a combination of supply and demand factors created a market imbalance and the price of frozen skipjack in Bangkok plummeted from US$1150/mt in August 1998 to US$380/mt in November 2000.

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[8] The increasing use of fish aggregating devices (FADs) when targeting skipjack substantially modifies the catch composition by species towards more bycatch of juvenile bigeye and yellowfin tunas, a major concern for tRFMOs (Dagorn et al. 2012; Hall and Roman 2013). Other bycatch species include oceanic sharks and other elasmobranches and many finfish species.

The major European and Asian ship owners, representing 65 % of purse-seine catches in the world, created the World Tuna Producers Organization (WTPO) after a first meeting in Paris in June 2000 (Morón 2002). Soon after, by late November 2000, they adopted voluntary reduction measures (effort reduction, catch limitation, market oriented measures and time-area closures), resulting in a spectacular price recovery within the following months (the price of frozen skipjack in Bangkok fetched 940 US$/mt in April 2001). This example supports the finding of unitary scale flexibility in the Bangkok cannery market that could result in effective price adjustment.

The implications of price and scale flexibility are important for fishery management, and market incentives, such as the market price's negative response to catch level changes, should be taken into greater consideration by regulatory bodies. The estimated unitary scale flexibilities for cannery grade skipjack and yellowfin tuna could support the economic benefit of global quota management control and of the impact of changes in fishing capacity and catch reduction on the value of total landings. With fishers' revenues held constant by a price-quantity scissor effect and the costs of fishing effort reduced, scarcity rent would increase and be partly re-distributed through compensation schemes (buyback and side payments) to promote capacity reduction. The success of quota control is also influenced by the possibility that fewer fish could ensure higher profit. If there is no loss in revenues and even potential profit increases resulting from lower harvest levels, the net present value of fishery resources would be maximized in the long run.

6 Conclusion

Economic incentives count when conserving renewable resources. The primary focus of the common resource literature, and especially the fisheries literature, is on property rights and the incentives they establish, and recent attention has been given to other margins. The relationship between catch limits and revenues, profits, and conservation has received insufficient attention, especially in globally integrated markets where local management measures can create counter-incentives to limit the "race for fish". This relationship centers on the price and revenue responsiveness to changes in aggregate quantities.

This paper shows that a global supply reduction of skipjack and yellowfin would be offset by a proportionate increase in price response that could keep fishers' revenue constant. This result has important consequences for tuna conservation policies. Catch limits for local and single species manage most industrial fisheries, and not all are subject to rights-based management. The search for other economic and conservation incentives whose effectiveness and political expedience can readily be conveyed to regulators and fishery participants provides an alternative, especially in the international arena where multilateral cooperation on management measures other than catch limits is difficult to obtain because of distributional impacts. One such unexploited incentive lies in the key relationship between changes in global catch limits and price responsiveness, which we explore in the context of global tuna fisheries. As well-defined as property rights, this catch limit-generated incentive may be among the most important in fisheries management and it is likely to be readily accepted by all parties involved. Additionally, non-market biodiversity conservation benefits can extend beyond the species of concern to bycatch species whose catches would also be reduced when the catch limits of target species are reduced. However, catch limit reductions may be counter-productive to generating desired economic incentives if market conditions favor price flexibility that is less than unity, in that price rises proportionately less than the output decreases.

This study confirms that management decisions need to be coordinated at the international level between RFMOs, as envisaged by the "Kobe process" (Allen 2010), in order to avoid adverse local or global spillovers generated by independent decisions in other management arenas. Tuna RFMOs can exploit comparatively flat areas of the yield-effort curves at high effort levels for several cannery grade tropical tuna species to conserve the resource and introduce a precautionary cushion without sacrificing revenues. In fact, when economic conditions are favorable, conservation measures can result in a boost in profits and rent.

References

Allen R (2010) International management of tuna fisheries: arrangements, challenges and a way forward. FAO Fisheries and Aquaculture Technical Paper 536, Rome

Anderson G, Blundell R (1983) Testing restrictions in a flexible dynamic demand system: an application to consumers' expenditure in Canada. Rev Econ Stud 50(3):397–410. doi:10.2307/2297672

Anderson RW (1980) Some theory of inverse demand for applied demand analysis. Eur Econ Rev 14(3):281–290. doi:10.1016/S0014-2921(80)80001-8

Asche F, Zhang D (2013) Testing structural changes in the U.S. whitefish import market: an inverse demand system approach. Agric Resour. Econ Rev 42(3):453–470

Barkin JS, Shambaugh G (eds) (1999) Anarchy and the environment: the international relations of common pool resources. State University of New York Press, Albany

Barten AP (1993) Consumer allocation models: choice of functional form. Empir Econ 18(1):129–158. doi:10.1007/BF01238883

Barten AP, Bettendorf LJ (1989) Price formation of fish: an application of an inverse demand system. Eur Econ Rev 33(8):1509–1525. doi:10.1016/0014-2921(89)90075-5

Berkes F, Hughes TP, Steneck RS et al (2006) Globalization, roving bandits, and marine resources. Science 311(5767):1557–1558. doi:10.1126/science.1122804

Bertignac M, Campbell HF, Hampton J, Hand AJ (2000) Maximizing resource rent from the western and central Pacific tuna fisheries. Mar Resour Econ 15(3):151–177

Brown MG, Lee JY, Seale JL Jr (1995) A family of inverse demand systems and choice of functional form. Empir Econ 20(3):519–530. doi:10.1007/BF01180680

Campbell HF (1998) Ocean-scale management of pelagic fisheries: economic and regulatory issues. Proceedings of an international workshop. In: Chakravorty U, Sibert J (eds) How many purse seiners should exploit the western Pacific tuna fishery?. Pelagic Fisheries Research Program, Joint Institute for Marine and Atmospheric Research, University of Hawaii at Manoa, Honolulu, pp 29–40

Chiang FS, Lee JY, Brown MG (2001) The impact of inventory on tuna prices: an application of scaling in the Rotterdam inverse demand system. J Agric Appl Econ 33(3):403–411

Clark CW (1990) Mathematical bioeconomics: the optimal management of renewable resources, 2nd edn. Wiley, New York

Copeland BR, Taylor MS (2009) Trade, tragedy, and the commons. Am Econ Rev 99(3):725–749. doi:10.1257/aer.99.3.725

Dagorn L, Holland KN, Restrepo V, Moreno G (2012) Is it good or bad to fish with FADs? What are the real impacts of the use of drifting FADs on pelagic marine ecosystems? Fish Fish 14(3):391–415. doi:10.1111/j.1467-2979.2012.00478.x

Eales J (1996) A further look at flexibilities and elasticities: comment. Am J Agric Econ 78(4):1125–1129

Eales J, Durham C, Wessells CR (1997) Generalized models of Japanese demand for fish. Am J Agric Econ 79(4):1153–1163. doi:10.2307/1244272

Finus M, Schneider R (2012) Scope and compatibility of measures in international fisheries agreements, Working Paper. Department of Economics, University of Bath, Bath

Food and Agriculture Organization of the United Nations (2012) FishstatJ database, Fisheries and Aquaculture Department, Rome. http://www.fao.org/fishery/statistics/software/fishstatj/en

Gordon HS (1954) The economic theory of a common property resource: the fishery. J Polit Econ 62:124–142

Grafton RQ, Arnason R, Bjorndal T et al (2006) Incentive-based approaches to sustainable fisheries. Can J Fish Aquat Sci 63(3):699–710. doi:10.1139/f05-247

Greene WH (2002) Econometric Analysis, 5th edn. Prentice Hall, Englewood Cliffs

Hall MA, Roman M (2013) Bycatch and non-tuna catch in the tropical tuna purse seine fisheries of the world. FAO Fisheries and Aquaculture Technical Paper 568, Rome, Italy

Houck JP (1965) The relationship of direct price flexibilities to direct price elasticities. Am J Agric Econ 47(3):789–792. doi:10.2307/1236288

Huang KS (1994) A further look at flexibilities and elasticities. Am J Agric Econ 76(2):313–317. doi:10.2307/1243633

Jeon Y, Reid C, Squires D (2008) Is there a global market for tuna? Policy implications for tropical tuna fisheries. Ocean Dev Int Law 39(1):32–50. doi:10.1080/00908320701641594

Jiménez-Toribio R, Guillotreau P, Mongruel R (2010) Global integration of European tuna markets. Prog Oceanogr 86(1–2):166–175. doi:10.1016/j.pocean.2010.04.022

Joseph JA, Squires D, Bayliff W et al (2010) Addressing the problem of excess fishing capacity in tuna fisheries. In: Allen R, Joseph JA, Squires D (eds) Conservation and management of transnational tuna fisheries. University of California at San Diego, San Diego, Department of Economics , pp 11–38

Just RE, Hueth DL, Schmitz A (2004) The welfare economics of public policy: a practical approach to project and policy evaluation. Edward Elgar, Cheltenham 712 pp

King RM (1987) The US tuna market: a Pacific islands perspective. In: Doulman DJ (ed) The development of the tuna industry in the Pacific islands region: an analysis of options. East-West Fisheries Science Center, NOAA Fisheries, Honolulu

Laitinen K, Theil H (1979) The Antonelli matrix and the reciprocal Slutsky matrix. Econ Lett 3:153–157

MacKinnon JG (1996) Numerical distribution functions for unit root and cointegration tests. J Appl Econ 11(6):601–618. doi:10.1002/(SICI)1099-1255(199611)11:6<3.0.CO;2-T

Miyake MP, Guillotreau P, Sun CH, Ishimura G (2010) Recent developments in the tuna industry: stocks, fishery, management, processing, trade and markets. FAO Fisheries and Aquaculture Technical Paper 543, Rome, Italy. http://www.fao.org/fishery/publications/technical-papers/en

Morón J (2002) The WTPO and its significance in the world tuna purse-seine fishery. SCTB15 Working Paper FTWG-6, Honolulu, Hawaii

Owen AD (2001) The Relationship between the world price for skipjack and yellowfin tuna raw material for canning and supply from the WCPO and FFA Member Countries EEZs. Forum Fisheries Agency, FFA Report 01/32, Pacific Islands Forum Fisheries Agency, Honiara, Solomon Islands. http://www.spc.int/DigitalLibrary/Doc/FAME/FFA/Reports/FFA_2001_032.pdf

Owen AD, Troedson DA (1994) The Japanese tuna industry and market. In: Campbell HF, Owen AD (eds) The economics of Papua New Guinea's tuna fisheries. Australian Centre for International Agricultural Research (ACIAR) Monograph, Canberra, pp 231–238

Park H, Thurman WN (1999) On interpreting inverse demand systems: a primal comparison of scale flexibilities and income elasticities. Am J Agric Econ 81(4):950–958. doi:10.2307/1244337

Segerson K, Zhou R (2014) Individual vs. collective quotas in fisheries management under uncertainty, Working paper. Department of Economics, University of Connecticut Storrs

Smith MD (2012) The new fisheries economics: incentives across many margins. Annu Rev Resour Econ 4:379–402. doi:10.1146/annurev-resource-110811-114550

Stigler GJ, Sherwin RA (1985) The extent of the market. J Law Econ 28(3):555–585

Sun CH (1999) Analysis of the market structure and price cointegration of the tuna raw material markets for tuna canneries in the world. Agric Econ 22:51–72 (in Chinese)

Sun CH, Hsieh MC (2000) Analysis of the price response of Taiwan tuna purse seine fishery in the frozen tuna raw material market in Thailand. J Fish Soc Taiwan 27:45–58 (in Chinese)

Sun CH, Hsu WH (1998) Analysis of the price cointegration across different countries for the frozen tuna sashimi market in Japan. Selected Paper of the Ninth International Conference of the International Institute of Fisheries Economics and Trade, Tromsø, Norway

Sun CH, Maunder MN, Aires-da-Silva A, Bayliff WH (2010) Increasing the economic value of the eastern Pacific ocean tropical tuna fishery: tradeoffs between longline and purse seine fishing. International

Workshop on Global Tuna Demand, Fisheries Dynamics and Fisheries Management in the Eastern Pacific Ocean, La Jolla, California, USA, May 13–14, 2010

Vestergaard N (2010) Principal-agent problems in fisheries. In: Grafton RQ, Hilborn R, Squires D, Tait M, Williams M (eds) Handbook of marine fisheries conservation and management. Oxford University Press, Oxford, pp 563–571

Webster DG (2015) Beyond the tragedy in global fisheries. MIT Press, Cambridge

Wessells CR, Wilen JE (1994) Seasonal patterns and regional preferences in Japanese household demand for seafood. Can J Agric Econ 42(1):87–103. doi:10.1111/j.1744-7976.1994.tb00008.x

Wilen JE (2000) Renewable resources economists and policy: What differences have we made? J Environ Econ Manag 39:306–327