Unintended consequences: The spillover effects of common property regulations

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A B S T R A C T

The closure of the Hawaiian longline swordfish fishery over the period 2001–2004, which was motivated by the protection of endangered sea turtles, created the elements of a natural experiment that allows identification of the market transfer of catch (and sea turtle bycatch) to other regions. This paper exploits the fact that the vessels in the Hawaiian longline fishery sell their catch in the US fresh swordfish market to analyze the pattern of changes in US fresh and frozen swordfish consumption both before and after the closure regulation was imposed. The mechanisms by which any unintended consequences on endangered sea turtles in other fishery locations in the world are shown to take place through the US swordfish market. At the estimated annual market transfer, a bootstrap analysis of the probability distribution of bycatch rates indicates that the regulation led to an additional 2882 sea turtle interactions at the sample means.

1. Introduction

Environmental regulations can have both intended and unintended effects. One type of unintended effect, known as market transfer effect, occurs when regional regulation to control externalities in one market leads to increased market production and environmental damages in another market. Given the current trend towards globalization of markets, regionalized environmental policies may alter trade flows with little effect on global production. The market transfer effect of regional environmental regulations has the potential to increase global environmental damages when, for example, the market transfer arises from a ban on production in a relatively "clean", regulated economy that shifts production to countries with little environmental controls.

This paper examines the market transfer effect of endangered sea turtle bycatch as a result of the closure of the Hawaiian pelagic longline swordfish fishery. Pelagic longlining, which is the most common method for targeting large swordfish for high-end fresh markets in the US, operates by attaching baited hooks to a horizontal line held afloat by buoys. These lines stretch up to a hundred kilometers across the ocean and are set at a shallow depth that facilitates the incidental bycatch of endangered sea turtles. In April 2001, the National Marine Fisheries Service (NMFS) entirely closed the shallow-set (swordfish-target) component of the Hawaii-based longline fishery in order to reduce the adverse effects of incidental bycatch on sea turtle populations.[1] Prior to the closure, the Hawaiian fishery distributed its product in the fresh segment of the swordfish market and represented 42% of the US swordfish catch and 19% of total US fresh swordfish consumption [1,2]. This closure, which impacted fresh swordfish supply but not frozen swordfish supply, forms the foundation for an experiment that allows the market transfer effect to be econometrically estimated for the shift in swordfish catch (and turtle bycatch) to other regions as a result of the regulation.

Not surprisingly, the rate at which various fisheries lead to the unintended death or injury of endangered sea turtles varies greatly, and this variation is at least in part attributable to differing degrees of fishery management and monitoring. For instance, over the period 1994–2001 preceding the closure of the Hawaii longline swordfish fishery, sea turtle bycatch rate averaged 0.17 turtles per mt of swordfish caught, whereas estimates for other major producers range from 0.8 to 1.2 turtles per mt of swordfish caught in Uruguay, 23.2 turtles per mt of swordfish in Brazil [4], and 1.58 turtles per mt of swordfish in South Africa [5].

[1] This closure remained in effect until March 2004, when the fishery was reopened under new restrictions. Since 2004, the Hawaii-based shallow-set fishery has operated with 100% federal observer coverage and very stringent limits on both the amount of fishing effort and the permissible level of sea turtle incidental bycatch [3].

Given both the wide variation in international bycatch rates and the trend towards freer global trade, understanding the magnitude of market transfer effects from regulation of the Hawaiian pelagic longline swordfish fishery is essential.

But pointing out the possibility of market transfer effects and quantifying them are two very different things. The estimation of market transfer effects, in general, is confounded by a number of variables. First, apart from regulation, there may be a high degree of annual variation in global production. Second, demand for the regulated good may change at the same time that the regulation takes place, particularly in cases where consumers are sensitive to an environmental issue, as may be the case of warnings about mercury levels in swordfish. And third, the regulated region often represents a small fraction of the global market, which confounds the identification of global changes that can be attributed to a regulation that constrains regional supply.

The closure of the Hawaiian longline swordfish fishery represents a unique opportunity to measure market transfer effects for two reasons. First, prior to the regulation, the Hawaiian longline fishery represented a substantial share of both the US swordfish catch and of total US fresh swordfish consumption [6,7]. Given the limitations on catch prevailing in the US Atlantic fishery, removing the Hawaiian catch from the US market led to substantial variation in the pattern of US swordfish trade. Second, and more fundamentally, US consumption of swordfish occurs in both a fresh and a frozen segment while the Hawaiian industry provides only fresh swordfish supply. This allows outside effects that influence US swordfish demand, for instance decreased demand over time resulting from Food and Drug Administration warnings regarding mercury levels in swordfish beginning in 2001, to identify the change in the quantity of fresh swordfish demand that occurred as a result of the Hawaiian closure.

Our empirical approach is framed as follows. First, we utilize the fresh and frozen components of the US consumer market to identify the magnitude of the market transfer effect in US swordfish imports. The separation of the two markets, fresh and frozen, allows a balanced panel for which Hawaiian swordfish closure impacts are entirely in the fresh market and the treatment group is whatever regions of the world filled the gap in the US fresh swordfish market through their exports to the US. Second, we examine the pattern of US swordfish imports and use this data to bootstrap the probability distribution of the market transfer to various fisheries outside the US as a result of the 2001–2004 Hawaiian fishery closure. Finally, we examine comparative bycatch rates for the Hawaii-based fishery and the shallow-set fisheries identified by the bootstrap analysis to provide a measure of the likely impact of sea turtle protective measures in Hawaii on overall sea turtle mortality. Our main finding is that the restriction of fishing effort in the Hawaii-based shallow-set longline fishery resulted in an estimated transfer of 1602 mt of swordfish catch to non-US fisheries. At the comparative bycatch rates indicated for those regions benefiting from the transfer of swordfish production, the market transfer effect of the regulation led to an additional 2882 sea turtle interactions at the sample means, with significant adverse impact on sea turtle injuries and mortality.

2. Background: the swordfish market in the 1990s

In the 1970s and 1980s, the Atlantic was the primary US swordfish fishery. This changed in 1990 as a result of swordfish fishing restrictions recommended by the International Commission for the Conservation of Atlantic Tuna (ICCAT) [8, pp. 92–93]. In response to the ICCAT report, in June 1991, the US established a total allowable catch (TAC) limit of 4163 mt and set a minimum size limit of 25 kg per fish [9], which caused a dramatic decline in swordfish landings. Between 1990 and 1991, US Atlantic landings dropped from 6603 to 3551 mt (46%) and the 10-year average of US Atlantic landings fell from 4196 mt per year over the period 1981–1990 to 2547 mt per year (39%) over the period 1991–2000 [10].

The decline in swordfish catch in the US Atlantic fishery was countered by a simultaneous increase in swordfish catch in the US Pacific fishery (see Fig. 1). In the 10 years before the regulation, the US Atlantic fishery comprised 76% of the US catch, while the US Pacific fishery comprised 24%, whereas, in the 10 years after the regulation, the US Atlantic fishery comprised 34% of the US catch and the US Pacific fishery comprised 66%.

Overall, the level of total domestic swordfish landings was virtually unaffected by the Atlantic regulation because US fishing effort was transferred from the Atlantic to the Pacific. Indeed, the total US swordfish catch continued to climb after 1990 in spite of the decrease in US Atlantic landings and did not decline until 1994—and then, only due to fluctuations in the US Pacific fishery landings.

The institution that mediated this transferred effect between the US Atlantic and US Pacific was the US swordfish market. Almost all US-caught swordfish is sold in the US [6]. Domestic swordfish landings are allocated entirely to fresh consumption [5,7,11,12], while the remainder of US swordfish consumption is a combination of imported fresh and frozen swordfish. For the entire period 1975–2006, there are no recorded exports of swordfish from the US [1]. This one-way flow of swordfish trade into the US suggests the potential for identifying the market transfer of fishing effort in response to a restrictive regulation in the US consumption and trade data.

3. The Hawaiian closure period, 2001–2004

Unlike the Atlantic regulation of 1991, the Hawaiian closure from 2001 to 2004 did not cause a transfer of swordfish catch to other US fisheries. Between April 2001 and March 2004, shallow longline sets were prohibited among Hawaiian-based vessels in the pelagic longline industry. Since shallow longline sets are the primary method for catching swordfish, this regulation brought Hawaiian swordfish catch virtually to zero, as represented in Fig. 2. Unlike the past US experience with a total catch limit in the US Atlantic fishery, it was not possible to offset this decline with increased landings elsewhere in the US. Furthermore, in 2001, it was known that the non-Hawaiian US Pacific longline fisheries would soon be implementing stricter regulations to protect sea turtles, and this knowledge probably limited the transfer of effort to those fisheries. In fact, other US Pacific swordfish landings decreased during 2001–2004, probably attributable to the fact that a portion of California swordfish landings before 2001 came from longline vessels registered in Hawaii.[2] Given US fresh swordfish consumption, any deficit left by the Hawaiian closure must necessarily be filled primarily by an increase in imports from other countries.

The key question is: How did this sudden drop in US swordfish production affect US swordfish consumption, US swordfish imports, and non-US swordfish catch? Because US swordfish production is virtually all sold in the fresh US market, any transferred effect of the Hawaii closure on non-US fisheries would occur through the mechanism of the US market, appearing as a change in US fresh swordfish imports. Therefore, our analysis begins with an assessment of the effect of the Hawaiian closure on

[2] Before 2001, 40 Hawaiian vessels were already unloading their catch in California for half the year. Only 20 of these vessels relocated to California in 2001 [6, pp. 19–23]. This explains why the California landings drop after 2001.

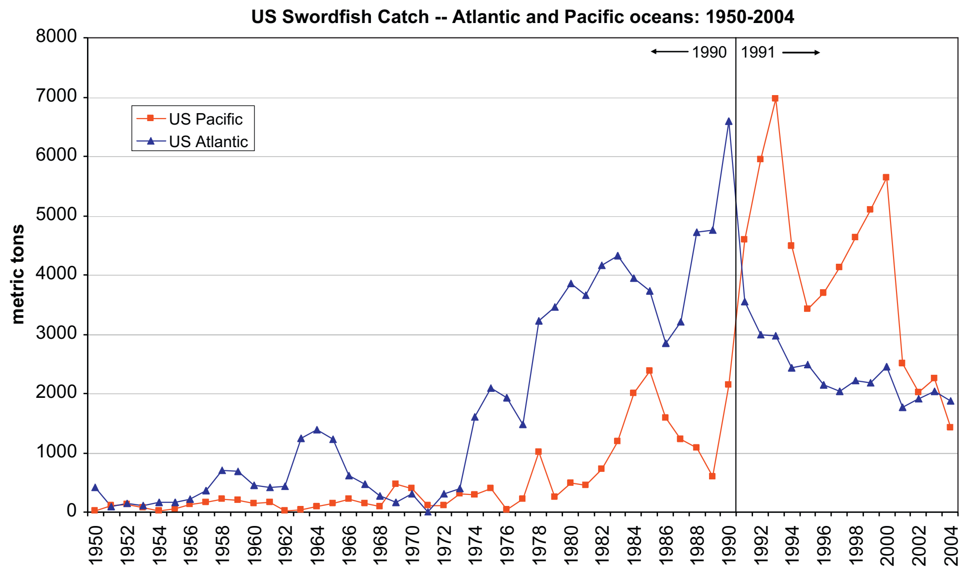

Fig. 1. US swordfish catch—Atlantic and Pacific oceans: 1950–2004. *Source*: FAO Fisheries Global Information System [10].

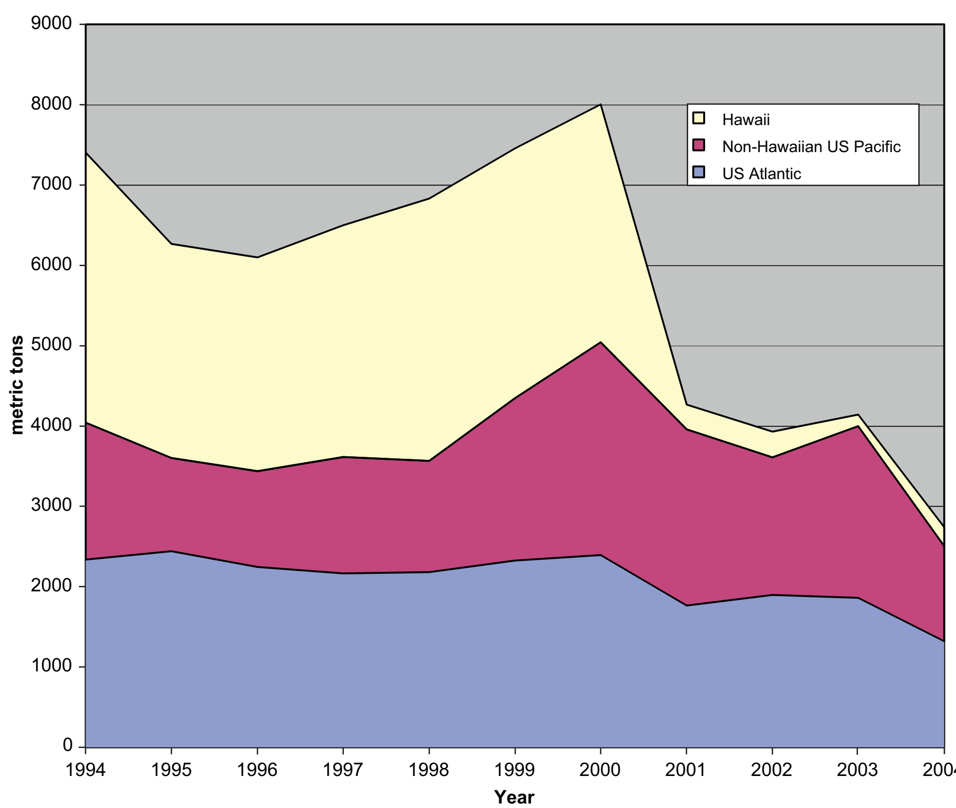

Fig. 2. Domestic swordfish landings by US production region, 1994–2004. *Source*: NOAA Fisheries [23].

US consumption, US imports and indirectly on swordfish catch and production in other parts of the world.[3]

Quantifying the effect of the Hawaiian closure on US consumption is complicated by confounding events. US swordfish consumption declined after 2000, as depicted in Table 1. The decline in US swordfish consumption between 1997 and 2004 occurred in spite of a decline in the 4-year average real ex-vessel price of swordfish ($1.48–$1.22)[4] and a corresponding increase in global consumption (103,562 mt per year over the period 1997–2000 to 108,705 mt over the period 2001–2004) [13]. To explain this decline in consumption, both demand- and supply-side effects must be assessed. It is possible that the decline in

[3] Another reason to begin with an analysis of US imports is the unreliability of global catch data collected by FAO. FAO data is apparently not uniformly reported by different countries, which makes inter-country comparisons difficult. In an independent study of this issue, Sarmiento [14, pp. 6–7] made the same selection.

[4] Ex-vessel prices for Hawaii reported by NOAA (http://www.pifsc.noaa.gov/wpacfin) are deflated by the US CPI (US Bureau of Labor Statistics).

Table 1
US Domestic swordfish consumption and its sources in the 4-year periods prior to and during closure of the Hawaiian shallow-set longline fishery[a]

Period	Year	Domestic production	Imports		Fresh US consumption	Total US consumption
		Fresh[b]	Fresh	Frozen		
Pre-closure	1997	6287	8477	7121	14,764	21,885
	1998	6779	8590	7692	15,369	23,061
	1999	7377	8677	5166	16,054	21,220
	2000	7912	8789	5525	16,701	22,226
	Mean	7089	8633	6376	15,722	22,098
During closure	2001	3891	9054	4644	12,945	17,589
	2002	3576	9921	5791	13,497	19,288
	2003	4087	8227	4923	12,314	17,237
	2004	2682	6727	4000	9409	13,409
	Mean	3559	8482	4839	12,041	16,880

Source: Domestic production [2]; Imports [1].

[a] Table 1 covers only the years 1997–2004 in order to compare equal time periods for the pre-closure and closure periods. To examine the sourcing of US swordfish imports, Table 1 uses NOAA trade data compiled by US Customs reports. This is the most accurate data available on fresh and frozen swordfish flows by country of origin into the United States; nonetheless, there is a discontinuity in the manner in which US import data on swordfish is recorded. Prior to 1997, swordfish imports were recorded as either fresh or frozen swordfish products. Beginning in 1997, three new categories of swordfish were coded in the data: frozen swordfish fillets, fresh swordfish steaks and frozen swordfish steaks. Prior to the introduction of these codes, cut swordfish products had been recorded as "unclassified fish fillets" (personal communication with Steve Koplin, NOAA). The new codes led to a tripling in the amount of frozen swordfish imports recorded by US Customs from 5140 mt in 1996 to 15,598 mt in 1997, which in turn caused a doubling of recorded US consumption (domestic production plus imports) from 10,982 mt in 1996 to 21,761 mt in 1997. Pre-1997 frozen swordfish imports were inflated using the results of a simple linear regression on a time trend to achieve comparability between pre- and post-1997 reporting codes.

[b] Virtually none of the domestically produced swordfish is sold frozen.

consumption could be partially the result of the reduction in supply from Hawaii caused by the 2001–2004 regulation. Alternatively, it could be the result of demand-side events in the US. The "Give Swordfish a Break" campaign, organized by Sea Web and the Natural Resources Defense Council, began in January 1998 in East Coast restaurants that eventually grew to a nationwide consumer boycott of North Atlantic swordfish. It was ended in 2000, but its effect may have carried into the closure period. In 2001, the FDA issued an advisory warning consumers of high levels of mercury in swordfish from both the Atlantic and Pacific. The mercury content of swordfish was also publicized by groups such as the Sea Turtle Restoration Network [15].

The international supply of swordfish is spatially flexible, which facilitates a transfer of fishing effort. Global migration of pelagic fishing fleets is common [11,16–18]. Several characteristics of the Hawaiian swordfish fishery would facilitate a movement of non-Hawaiian fishers into the space left by the regulated Hawaiian fishers. First, Hawaiian fishers may move to non-Hawaiian fisheries, or they may sell their boats and gear to non-Hawaiian fishers, which reduces startup costs for new fishers entering the market. Such movements have occurred in the past [7]. Second, swordfish is a highly migratory species, and there are a small number of stocks in the Pacific [7,19]. This would mean that the reduction of catch by Hawaiian fisheries would cause an increase in fish available to other fisheries, which would increase their catch per unit effort, and attract more fishers to the market. Third, the fishing grounds frequented by Hawaiian longliners are largely international waters, and longliners often travel thousands of miles in fishing expeditions. Therefore, any decrease in effort by Hawaiian fishers might be compensated by foreign fishers working the same fishing grounds [7].

Migrations of longline swordfish vessels are also common. In the late 1980s, responding to declining swordfish stocks in the Atlantic, almost 100 longline vessels—along with their crews—-moved from the US East Coast to Hawaii [16]. Between 1989 and 1991, approximately 20 vessels moved from the US west coast to Hawaii [17]. In 1993, longline vessels moved from the US ports in the Gulf of Mexico to California, increasing the California fleet from 3 to 31 [6]. In 2000, 40 Hawaiian vessels were unloading their swordfish catch in California ports [6], and after the 2001 Hawaiian fishery closure 20 Hawaiian vessels relocated to California [20].

If any swordfish catch were transferred to non-US fisheries during 2001–2004, where did it go? Since any transferred effect would be mediated by the US market, the first step in answering this question is to analyze changes in US swordfish imports during the period of the Hawaiian closure.

There are two obvious methods to allocate the transferred swordfish catch among regions: (a) distribute the catch among all regions in proportion to the amount the US imported from each region; (b) distribute the catch among only those regions from which there is a economical and statistical significant increase in US imports during the period of Hawaiian closures. Our analysis adopts the second approach. Because fisheries differ in their labor and technology costs, the status of their stocks, and other factors, some fisheries would have responded more readily than others to the sudden increase in demand facing these potential supply sources. In general, the fishing effort could have shifted elsewhere in the Pacific Ocean and/or the Indian Ocean, but not to the Atlantic Ocean. The cap on allowable catch in the Atlantic since 1995 eliminates an appreciable unintended Atlantic Ocean effect.

In identifying the specific location of the transferred swordfish catch, our analysis uses regions instead of countries. The country that exports swordfish to the US is not necessarily the country that caught the fish. After the fish is caught, it might be landed in a country different from the flag of the vessel that executed the catch, and after landing, it might be exported to another country before being exported to the US. There is no systematic tracking of swordfish catch in the years under investigation, so there is no way to be certain of the fishery that caught the fish imported into the US.[5] Accordingly, we have grouped countries into regions to minimize the effect of swordfish being transported across national boundaries.

To isolate those regions that responded most readily to an increase in US demand for foreign swordfish, we econometrically estimated a simultaneous system of demand and supply equations which represent the US swordfish market. Within the

[5] Personal communication, Michael Hinton, IATTC, 22 June 2007.

system, we specified a separate fresh import supply equation for each region and included, along with current prices and a measure of fleet movement, a dummy variable representing the period during which the Hawaiian fishery was closed (2001–2004). Our measure of fleet movement or flexibility (see Appendix A) is a proxy variable designed to partially capture the entry and exit of the pelagic fishing fleet from one region of the world to all other regions.

4. Empirical model

The preceding analysis provides anecdotal evidence of a transferred effect, but it also reveals a potentially critical confounding factor. The decline in swordfish consumption may be the result of the Hawaiian closure, but it could also be the result of the demand-side forces, or some combination of the two. To sort out these confounding factors, it is necessary to construct a market model for swordfish demand and import supply.

The degree to which the Hawaiian closure would cause an increase in US imports may be affected by the own-price elasticity of demand for swordfish. If the demand is price inelastic, this increases the likelihood of a transferred effect. Prior studies on demand for finfish have found that the demand is price inelastic. Consumer demand for high-value fresh fish (tuna, yellowtail, swordfish, flatfish, sea bream) has been analyzed for Japan. Japanese demand for fresh fish is important, because annual per capita consumption of high-value finfish in Japan (33.1 kg) is twice as high as per capita annual consumption in the E.U. (15.4 kg) and nearly three times as high as that in the US (13.3 kg). There is general agreement in these studies that demand for fresh fish is price inelastic, and recent estimates of the price elasticity of high-value fresh fish in Japan are in range −0.46 to −0.99 [21]. Studying the US market, Wellman [22] found that, "with the exception of shellfish, demand for the various fish products is relatively inelastic."

A key fact that enables us to partially distinguish demand from supply forces is that the Hawaiian catch was virtually all sold fresh in the US market. As a result, if the Hawaiian closure were to affect US swordfish consumption at all, it would affect the consumption of fresh and frozen swordfish differently. It might cause a decrease in fresh consumption, but it would not cause a decrease in frozen consumption. By contrast, the demand-side forces—in particular, the FDA advisory—would result in proportional effects in both fresh and frozen consumption. Based on this reasoning, we specify two demand equations, one for US fresh swordfish and one for US frozen swordfish, and include in both equations a dummy variable called "FDA" that covers the years 2001–2005. If the coefficient of the FDA variable is negative and significant in the fresh model and either insignificant or positive in frozen demand, this would indicate that the decline in frozen consumption was due at least in part to the Hawaiian closure.

In structuring our empirical model, we are guided by the work of Dale Squares and his colleagues [23,24], and the work on international trade for other fish species by Kinnucan and Myrland [4,25,26] as well as Sarmiento [14] on swordfish. In the latter model, Sarmiento [14] followed Enders et al. [27] in estimating a transfer function for monthly individual country imports. Unfortunately, his analysis does not include swordfish price effect or any measure of fishing fleet flexibility for each country as explanatory variables. Moreover, given the dominant role of the US dollar as an international currency, there is no reason to expect exchange rates from convertible to non-convertible currencies to have a significant multiplicative or additive effect [28] on import supply. The important question answered by the fresh import supply equations is whether the Hawaiian closure had a significant effect on import supply from any region from which the US imports fresh swordfish.

In specifying the market structure, all prices were measured at the border and the signals from current prices effect both demand and supply to the US fresh and frozen swordfish market. There are, of course, a number of serious data limitations that reduce the richness of our specified model. In particular, there is no available stock data on swordfish in various parts of the world that can be included in the model. In addition, any proxy for income within the US market over the relevant period turns out to be basically nothing more than a time trend. In any event, prices are jointly determined by both demand and supply forces, where demand is specified internally within the borders of the United States, and supply responsiveness is largely confined to the rest of the world.[6]

Given that the US fresh swordfish market is the mechanism through which any potential transferred effect might occur, the model to be estimated is composed of twelve equations. The model is designed with separate fresh import supply equations for each region that can feasibly respond in order to identify which regions, if any, significantly and economically increased exports to the US during the closure period. Eqs. (1)–(9) are the behavioral equations, Eq. (10) is an identity accounting the supply of fresh swordfish from all sources, and Eqs. (11) and (12) are equilibrium conditions:

$$Q_{i,t}^{D,F} = f(P_{i,t}^{F,SWO} | P_{j,t}^{F,SAL}, I_t^{US}, FDA_{i,t}) \tag{1}$$

$$Q_{i,t}^{D,Z} = f(P_{i,t}^{Z,SWO} | P_{j,t}^{Z,SAL}, P_{i,t}^{F,SWO}, I_t^{US}, FDA_{i,t}) \tag{2}$$

$$Q_{i,t}^{S,F,EPO} = f(P_{i,t}^{F,EPO} | F_{t-1}^{EPO}, HAWAII_{i,t}) \tag{3}$$

$$Q_{i,t}^{S,F,CAR} = f(P_{i,t}^{F,CAR} | F_{t-1}^{CAR}, HAWAII_{i,t}) \tag{4}$$

$$Q_{i,t}^{S,F,NWPAC} = f(P_{i,t}^{F,NWPAC} | F_{t-1}^{NWPAC}, HAWAII_{i,t}) \tag{5}$$

$$Q_{i,t}^{S,F,SAATL} = f(P_{i,t}^{F,SAATL} | F_{t-1}^{SAATL}, HAWAII_{i,t}) \tag{6}$$

$$Q_{i,t}^{S,F,SAPAC} = f(P_{i,t}^{F,SAPAC} | F_{t-1}^{SAPAC}, HAWAII_{i,t}) \tag{7}$$

$$Q_{i,t}^{S,F,SWPAC} = f(P_{i,t}^{F,SWPAC} | F_{t-1}^{SWPAC}, HAWAII_{i,t}) \tag{8}$$

$$Q_{i,t}^{S,Z} = f(P_{i,t}^{Z} | Q_{t-1}^{S,Z}, HAWAII_{i,t}) \tag{9}$$

$$\begin{aligned} Q_{i,t}^{S,F} = {} & Q_{i,t}^{S,F,EPO} + Q_{i,t}^{S,F,CAR} + Q_{i,t}^{S,F,NWPAC} + \cdots \\ & + Q_{i,t}^{S,F,SWPAC} + Q_{i,t}^{S,F,ROW} + Y_{i,t}^{F,DOM} \end{aligned} \tag{10}$$

$$Q_{i,t}^{D,F} = Q_{i,t}^{S,F} \tag{11}$$

$$Q_{i,t}^{D,Z} = Q_{i,t}^{S,Z} \tag{12}$$

Eq. (1) specifies US demand for fresh swordfish, where ${Q_{i,t}}^{D,F}$ is fresh swordfish purchased in the US; ${P_{i,t}}^{F,SWO}$is the landed price of fresh swordfish measured from US Department of Commerce trade data, in constant 2000 dollars; ${P_{j,t}}^{F,SAL}$ is the landed price of fresh salmon measured from US Department of Commerce trade data, in constant 2000 dollars; ${I_{i,t}}^{US}$is US GDP per capita, in constant 2000 dollars; and $FDA_{i,t}$ is a dummy variable controlling for the US Food and Drug Administration's (FDA) announcements

[6] A much simpler model was initially specified, in which demand and supply forces were represented in a recursive system. This specification was rejected in large part because of the empirical evidence that appears in the literature arguing that current prices, not lag prices, simultaneously influence both demand as well as supply for various fish species.

regarding mercury levels in swordfish, which began in 2001. The "Give Swordfish a Break" campaign did not have a measurable (significant) effect on either fresh or frozen US demand.

Eq. (2) specifies US demand for frozen swordfish, where ${Q_{i,t}}^{D,Z}$ is frozen swordfish purchased in the US; ${P_{i,t}}^{Z,SWO}$ is the landed price of frozen swordfish measured from US Department of Commerce trade data, in constant 2000 dollars; ${P_{j,t}}^{Z,SAL}$ is the landed price of frozen salmon measured from US Department of Commerce trade data, in constant 2000 dollars; ${P_{i,t}}^{F,SWO}$is the landed price of fresh swordfish measured from US Department of Commerce trade data, in constant 2000 dollars; ${I_{i,t}}^{US}$is US GDP per capita, in constant 2000 dollars; and ${FDA_{i,t}}^{D}$ is the same dummy variable described above for Eq. (1).

Eqs. (3)–(8) specify the import supply of fresh swordfish from the countries within the aggregated six ocean regions examined: the Central Eastern Pacific Ocean (EPO); the Caribbean (CAR); the Northwest Pacific (NWPAC); South America Atlantic (SAATL); South America Pacific (SAPAC); and Southwest Pacific (SWPAC). Each of the fresh import supply equations is specified as a function of the current price and fleet flexibility. Using Eq. (3) as an example: ${Q_{i,t}}^{S,F,EPO}$ is the quantity of fresh swordfish imported from countries in the Central Eastern Pacific region; ${P_{i,t}}^{F,EPO}$ is the current, landed price of imported fresh swordfish from the Central Eastern Pacific Ocean region measured in constant 2000 dollars; F_{t-1}^{EPO} represents the flexibility of fishing fleets operating in the Central Eastern Pacific ocean with respect to the other ocean regions from where their catch is sourced, as measured from the FAO data; and $HAWAII_{i,t}$ is a dummy variable controlling for closure of the Hawaiian swordfish fishery during 2001–2004.

Given that domestic swordfish catch is sold entirely as fresh product, the supply of frozen swordfish to the US market is sourced entirely through imports. It follows that while Eq. (9) is the *import* supply of frozen swordfish to the US market, it also represents the complete supply of frozen swordfish to the US market. Eq. (9) specifies the supply of frozen swordfish to the US market, where ${Q_{i,t}}^{S,Z}$ is the quantity of frozen swordfish imported from all countries; ${P_{i,t}}^{S,Z}$ is the current landed price of frozen swordfish as measured in constant 2000 dollars; $Q_{i,t-1}^{S,Z}$ is the quantity of frozen imports during the preceding year; and $HAWAII_{i,t}$ is a dummy variable controlling for closure of the Hawaiian swordfish fishery during 2001–2004.

Eq. (10) is an identity accounting the composition of fresh swordfish supplied to the US market. Fresh swordfish supply is measured by the addition of the dependant variables in Eqs. (3)–(8), and two exogenous variables not specified in the behavioral equations within the system, ${Q_{i,t}}^{S,F,ROW}$, and ${Y_{i,t}}^{F,DOM}$. Fresh swordfish imports from the rest-of-world is measured by ${Q_{i,t}}^{S,F,ROW}$. Rest-of-world includes Southeast Asia, Africa, Europe and the Indian Ocean regions. Swordfish were not imported from these regions in each year during the data series used to estimate the behavioral equations, and as a result, imports from these regions are treated as pre-determined.[7] Domestic fresh swordfish supply, ${Y_{i,t}}^{F,DOM}$, is also treated as pre-determined because of the TAC in place for the Atlantic Ocean currently constrains the supply from this source and regulation in the Hawaiian region serves the same purpose during the closure/treatment period.

Eqs. (1)–(10) combined with Eqs. (11) and (12), the equilibrium conditions, represent the closed system. The quantity of fresh swordfish demanded is equated to the quantity of fresh swordfish supplied in Eq. (11), while the quantity of frozen swordfish demanded is equated to the quantity of frozen swordfish supplied by Eq. (12).

Eqs. (1) and (2) are standard structural demand equations. Although fresh swordfish is thought to be a substitute for frozen swordfish, the data show that the products are not gross substitutes. The literature on substitution between fresh and frozen products of the same fish species has not come to any conclusion on the degree of substitution or complementarity. Asche et al. [29] found fresh and frozen salmon to be gross substitutes using data from the EU market, while Wellman [22] found fresh and frozen finfish to be gross compliments. Due to exporters' ability to move fresh and/or frozen product to various markets, fresh import supply is specified as a function of current prices. Frozen import supply, represented in by Eq. (9), is also specified as a function of current prices in addition to lagged frozen import levels. We include lagged frozen imports in the frozen import supply equation because of the stickiness of frozen swordfish imports and the apparent dominance of relationship-specific trade. The fleet flexibility variable, $F_{i,t-1}^{(region)}$, is computed based on fleet movements in each fresh import supply region and measured as the first difference in order to represent the annual change in the fleet presence in each region. The complete definition, data source(s), and basic summary statistics of each variable included in the structural model are presented in Appendix A.

The behavioral equations within the system are estimated simultaneously by three-stage least squares (3SLS) and using annual data covering 1990–2005. The motivation behind 3SLS is sourced from the need to control for the joint determination of quantity and price in the demand and supply equation supply equations represented in Eqs. (1)–(9). A quick review of the system reveals that each equation satisfies the necessary conditions for identification, in fact overidentification. The actual econometric estimates for each of the behavioral equations are presented in the following equations:

$$\begin{aligned} Q_{i,t}^{D,F} = &-\underset{(959.54)}{3783.96}P_{i,t}^{F,SWO} + \underset{(1838.92)}{119.77}P_{j,t}^{F,SAL} + \underset{(158.26)}{1400.53}I_t^{US} \\ &-\underset{(2799.77)}{13045.03}FDA_t, \quad R^2 = 0.975 \end{aligned} \tag{13}$$

$$\begin{aligned} Q_{i,t}^{D,Z} = &-\underset{(140.07)}{3948.12}P_{i,t}^{Z,SWO} + \underset{(539.16)}{749.70}P_{j,t}^{Z,SAL} + \underset{(392.31)}{2867.23}P_{i,t}^{F,SWO} \\ &+\underset{(57.22)}{491.75}I_t^{US} - \underset{(1038.04)}{6079.86}FDA_t, \quad R^2 = 0.963 \end{aligned} \tag{14}$$

$$\begin{aligned} Q_{i,t}^{S,F,EPO} = &\underset{(1234.28)}{874.05} + \underset{(402.57)}{701.47}P_{i,t}^{S,F,EPO} + \underset{(5885.04)}{16591.43}F_{t-1}^{EPO} \\ &+\underset{(826.55)}{3532.12}HAWAII_t, \quad R^2 = 0.536 \end{aligned} \tag{15}$$

$$\begin{aligned} Q_{i,t}^{S,F,CAR} = &\underset{(306.74)}{1715.72} - \underset{(83.85)}{290.28}P_{i,t}^{S,F,CAR} - \underset{(1689.46)}{4030.43}F_{t-1}^{CAR} \\ &-\underset{(115.79)}{275.99}HAWAII_t, \quad R^2 = 0.323 \end{aligned} \tag{16}$$

$$\begin{aligned} Q_{i,t}^{S,F,NWPAC} = &\underset{(464.32)}{2145.60} + \underset{(96.13)}{48.87}P_{i,t}^{S,F,NWPAC} + \underset{(1190.22)}{3914.52}F_{t-1}^{NWPAC} \\ &-\underset{(320.72)}{174.49}HAWAII_t, \quad R^2 = 0.131 \end{aligned} \tag{17}$$

[7] Fresh swordfish imports from the regions identified as rest-of-world were just 6.8% of US fresh imports. While fresh imports from the Africa region alone represented 4.96% of US fresh imports during 1990–2005, average annual imports from that region were statistically equivalent before and during the closure of the Hawaiian fishery.

$$Q_{i,t}^{S,F,SAATL} = \underset{(828.95)}{6530.60} - \underset{(377.18)}{1989.01}P_{i,t}^{S,F,SAATL} - \underset{(5338.30)}{261.46}F_{t-1}^{SAATL} + \underset{(687.65)}{557.69}HAWAII_t, \quad R^2 = 0.303 \tag{18}$$

$$Q_{i,t}^{S,F,SAPAC} = \underset{(1502.26)}{8706.49} - \underset{(365.34)}{1251.48}P_{i,t}^{S,F,SAPAC} + \underset{(4777.65)}{16285.13}F_{t-1}^{SAPAC} - \underset{(865.75)}{3018.44}HAWAII_t, \quad R^2 = 0.229 \tag{19}$$

$$Q_{i,t}^{S,F,SWPAC} = \underset{(670.02)}{2058.46} - \underset{(209.27)}{319.13}P_{i,t}^{S,F,SWPAC} + \underset{(10177.14)}{20376.75}F_{t-1}^{SWPAC} + \underset{(559.46)}{1388.15}HAWAII_t, \quad R^2 = 0.309 \tag{20}$$

$$Q_{i,t}^{S,Z} = \underset{(2474.64)}{27739.87} - \underset{(509.52)}{4439.94}P_{i,t}^{S,Z} + \underset{(0.07)}{0.02}Q_{i,t-1}^{S,Z} - \underset{(1349.71)}{6286.80}HAWAII_t, \quad R^2 = 0.715 \tag{21}$$

Each of the estimated coefficients in Eqs. (1) and (2) is consistent with economic theory and is highly significant for the variable of crucial relevance, namely *FDA*. The estimated US swordfish demand equations are consistent with the argument that there is a transferred effect due to the Hawaiian regulation. First, the estimated equations show that the US demand for swordfish is price inelastic. The own-price elasticity for fresh swordfish during the full period (1990–2005) is −0.40, and −0.38 for the Hawaiian fishery closure period (2001–2004).[8] Second, the coefficient on the FDA variable is negative and significant in both the frozen and fresh swordfish demand equations. The significant results for the FDA variable for *fresh* swordfish is consistent with the argument that demand declined as a response to the FDA advisory; however, it may also be consistent with the argument that fresh swordfish consumption declined as a result of the Hawaiian fishery closure. But the significant results obtained for the FDA variable for *frozen* swordfish cannot be explained by the Hawaiian closure. The Hawaiian swordfish catch was all sold fresh, so the drop in Hawaiian swordfish production would not have decreased the US consumption of frozen swordfish.

Further support for a transferred effect may be found by measuring the decline in US fresh and frozen swordfish consumption that occurred after 2000. Table 2 reports the average fresh and frozen consumption before and during the Hawaiian closure, and it calculates the percentage decline of each. This data shows that US fresh and frozen consumption declined at almost the same rate. This indicates that, while demand-side forces pushed both fresh and frozen consumption down, the Hawaiian closure did not have any additional effect on fresh consumption. After correcting for the downward shift in demand, the Hawaiian fresh swordfish supply was completely offset by an increase in foreign fresh swordfish supply.

Note that Eqs. (3) and (5), the fresh import supply sourced from the Central Eastern Pacific Ocean (3) and the Northwest Pacific (5), are the only fresh import supply equations where the estimated coefficient on the price variable is consistent with economic theory. The estimated coefficient on *HAWAII* is positive and significant in Eq. (3), but not significant in Eq. (5). Therefore, the results of the estimated fresh import supply equations show that the Central Eastern Pacific Ocean is the only likely region to which the Hawaiian fresh swordfish catch was transferred, i.e., the effective treatment group. The regions represented in Eqs. (4) and (6)–(8) are not considered as potential outlets for the market transfer of the Hawaiian fresh swordfish catch, because they are unresponsive to positive price signals. The abundance of swordfish in these regions may influence export behavior of the nearby nations more than prices offered in any potential market outlet. As previously noted, a stock variable was not included in Eqs. (3)–(8) due to the lack of time-series data on the stock of swordfish in each of the ocean regions from which fresh imports are sourced. Hinton and Maunder [30] report that annual swordfish catch in the eastern Pacific Ocean is below the maximum sustainable yield of the swordfish stocks identified in that region. This could well explain the positive coefficient on the landed price in Eq. (3).

The effect of the Hawaiian fishery closure variable in the import supply is highly significant and corroborates the demand equation results. In particular, Eq. (15) reports that the average increase in imports from the Central Eastern Pacific countries is approximately 3.352 million pounds (1602 t) of fresh swordfish per year, after netting out the price and fleet flexibility effects. Aside from the constant term, all the variables explaining fresh import supply sourced from the Central Eastern Pacific Ocean in Eq. (15) are significant and are signed as expected. Note that for the other import regions for which the closure variable is positive, the impact on fresh import supply is less than one-third (the case of the southwest Pacific) and less than one-sixth (the case of the South American Atlantic) than the impact on Central Eastern Pacific Ocean.

It is possible that there could be an increase in US swordfish imports from particular regions without an increase in swordfish production in that region, i.e. a shifting of relatively stable production. For this reason, we examine production data from the Inter-American Tropical Tuna Commission (IATTC), which represents the most accurate source of data on swordfish catch in various regions of the world. For example, since countries in Central America had significant swordfish catch in the Southern EPO (e.g., Panama), the entire EPO is the appropriate region for this analysis. As shown in Table 3, there was an increase in swordfish catch in the EPO during the Hawaiian closure (2001–2004), the increase was concentrated in the Southern EPO (south of 5° longitude), and it was statistically significant at the 99% confidence level.

5. Transferred effects

To estimate the degree of market shifting, we compare the actual fresh imports in the years 2001–2004 to the expected fresh imports absent the 2001–2004 regulation ("but-for fresh imports"). Actual fresh imports minus but-for fresh imports equals the estimated quantity of swordfish supply transferred to foreign fisheries. The but-for fresh imports are estimated under three separate demand conditions.

The methodology for estimating but-for fresh imports is based on the estimated fresh import supply equations of our structural model. The model found that the Hawaiian closure (as represented by the variable *HAWAII*) had a significant and acceptable economic effect on US imports from the Central Eastern Pacific region. To estimate the US fresh imports from this region in the absence of the Hawaiian closure, the *HAWAII* variable was set to zero, and the import supply equation was used to calculate the but-for US imports from the Central Eastern Pacific. Since our analysis found that the Central Eastern Pacific region is the only region with a significant increase in exports to the US during the period of the Hawaiian closure and jointly revealed a positive and

[8] Elasticities are computed at the mean values for quantity purchased and landed price. Results of model estimation using a double-log functional form generate an own-price elasticity for fresh swordfish of −0.14 for the full period.

Table 2
Average fresh and frozen US swordfish consumption before and after Hawaiian closure

	Average swordfish consumption (mt)		
	Pre-closure 1997–2000	Closure 2001–2004	Percentage decline
US fresh consumption	15,722	12,041	23
US frozen consumption	6376	4839	24
US total consumption	22,098	16,881	24

Table 3
Swordfish catch in the EPO: results of *t*-test

Ocean	Mean annual catch (mt)		Unpaired two-sample mean comparison test: Pr ($\lvert T\rvert > \lvert t\rvert$)[a]
	1997–2000	2001–2004	
EPO catch (all gear)	9445	16,939	0.001
Southern EPO catch (all gear)	7554	13,755	0.003

Sources: Inter-American Tropical Tuna Commission (IATTC) [30,39].

[a] Based on the results of the two-sample variance comparison test (*F*-test), each two-sample mean comparison test (*t*-test) was conducted assuming equal sample variance.

significant estimated coefficient on the current landed price variable, it is reasonable to conclude that much of transferred swordfish catch is located in this region. Accordingly, the transferred swordfish catch is equal to the difference between actual and but-for US imports from the Central Eastern Pacific region.

We estimated the degree of market shifting under three different demand conditions. First, we estimated it under the actual demand conditions. This initial estimate, while useful, may not be generalizable since the US demand was declining due to unusual demand-side factors that may not be sustainable. Therefore, we also estimated the degree of market shifting that would have occurred under two different "normal" demand conditions, where the US demand was not declining.

Under actual demand conditions, the market shifting caused by the Hawaiian closure is equal to the average annual actual fresh US imports from 2001 to 2004 minus the average annual but-for fresh imports, where the but-for fresh imports is equal to the amount of fresh swordfish the US would have imported but-for the Hawaiian closure. Under normal demand conditions, the market shifting would have been higher because total US fresh consumption would have been higher during 2001–2004. To estimate what total US fresh consumption would have been during 2001–2004 under these normal conditions, the US fresh demand equation was used with the FDA variable set to zero. Given this estimate of total US fresh consumption, there are two methods for calculating the transferred catch which represent two different market conditions.

The first of these methods is labeled "normal demand with increased domestic production." It assumes that, in the absence of the FDA advisory, US domestic production from non-Hawaiian fisheries during 2001–2004 would have been higher than it was in the presence of the FDA advisory. Under this method, the transferred swordfish catch is estimated to be 2373 mt.

The second method is "normal demand without any change in domestic production." It assumes that, in the absence of the FDA advisory, US production from non-Hawaiian fisheries during 2001–2004 would have been the same as it was in the presence of the FDA advisory. This is a reasonable specification because, as shown in Table 1 and Fig. 2, non-Hawaiian domestic production did not increase in response to Hawaiian closures, possibly due to their already having reached regulatory limits. Under this method, actual fresh domestic catch quantities are used without modification (under the assumption that non-Hawaiian domestic production is at its regulatory limit). For this method, the transferred swordfish catch is estimated to be 2712 mt.

Fig. 3 represents the results of our econometric methodology of calculating the transferred swordfish catch for actual demand conditions. As represented in Fig. 3, over the period 2001–2004 of Hawaiian industry closure, the actual US fresh imports are greater than the but-for import level of fresh swordfish from foreign markets by an average of 1602 mt per year. For this estimate, a 95% confidence interval of the transferred catch is 868–2337 mt (see Appendix B for the full analysis).

What are the effects of the swordfish market transfer on endangered sea turtles? The average net effect on sea turtles (NST) is calculated using the following equations:

$$NST = SE - BFHT \tag{22}$$

$$SE = (SSC/AWS\,CPUE^{C})\,B_yR^{C} \tag{23}$$

$$BFHT = (SSC/AWS\,CPUE^{h})\,B_yR^{h} \tag{24}$$

where *SE* is the average annual increase in sea turtle interactions attributable to the transferred swordfish catch; *BFHT* is the average annual number of sea turtle interactions that would have occurred in the Hawaiian swordfish fishery had it not been closed; *SSC* is the average annual amount (in metric tons) of swordfish that would have been caught in the Hawaiian fishery if not for the closure, but that was instead caught in the Central Eastern Pacific region; *AWS* is a parameter used to convert metric tons of swordfish into number of swordfish; $CPUE^{h}$ is the number of swordfish caught per 1000 hooks in the Hawaiian fishery; $CPUE^{C}$ is the number of swordfish caught per 1000 hooks in the Central Eastern Pacific fisheries; B_yR^{h} is the number of sea turtle interactions per 1000 hooks in the Hawaiian fishery; and B_yR^{C} is the number of sea turtle interactions per 1000 hooks in the Central Eastern Pacific fisheries.

The catch per unit of effort in Hawaii ($CPUE^{h}$) and the bycatch rate in Hawaii (B_yR^{h}) can be derived using values from the Hawaiian fishery during the period before the Hawaiian

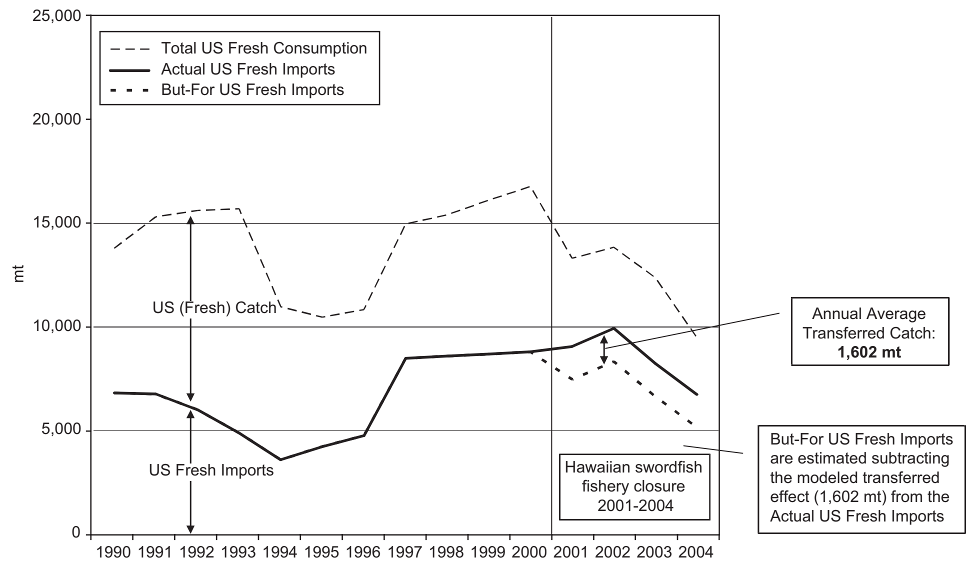

Fig. 3. Estimated transferred swordfish catch—actual demand conditions.

closure.[9] The remaining variables in (22)–(24) were derived using the best available data, as described in Table 4.

For *SSC*, under actual demand conditions, transferred swordfish catch was 1602 mt (95% CI 868–2337 mt). For *AWS*, in the absence of specific data on fish weight for the Central Pacific Region, we used data on the average weight of a swordfish caught by the Hawaiian swordfish fishery. This is a conservative approach because the Hawaiian fishery, being a dedicated swordfish fishery, is likely to catch relatively large swordfish. This is evidenced by the fact that, in those years when the Hawaiian fishery had the highest percentage of swordfish-dedicated trips, the average size of swordfish caught by the fishery was greatest [32, pp. 3–47]. For $CPUE^C$, we used the total number of fish from all target species to calculate the CPUE, rather than restrict it to swordfish, because it would have been difficult to separate out the portion of the turtle bycatch attributable to swordfish catch. The calculated CPUE for the Central Eastern Pacific region is 15.29 fish/1000 hooks (95% CI 10.44–21.15 fish/1000 hooks).[10] For B_yR^h, the bycatch rate in the period 2004–2006 is significantly lower than the bycatch rate in the period 1994–2002 [31, pp. 6–7]. The rates for the two periods are listed in Table 5.

These rates are based on a large number of observations. The method of collecting the data is reliable and thorough—indeed, in 2004–2006 the swordfish longline fishery had 100% onboard observer coverage. For B_yR^C, unfortunately there was no attempt to randomly sample fishing locations. The purpose of the IATTC research was not to estimate average bycatch rates but to compare the effects of circle hooks on bycatch rates. When a region produced low bycatch rates, the researchers often moved to other regions to collect data [33]. On the other hand, bycatch rates throughout the region are locally variable in space and time [33], so low bycatch rates for a particular region in the past are not necessarily a predictor of low bycatch rates for that area in the future.

A comparison of the IATTC data for Costa Rica with other bycatch data from Costa Rica indicates that the IATTC data generates bycatch estimates that are conservative [34, p. 62; 35, p. 2; 36]. In addition to the IATTC study, one other study was used to estimate bycatch in this region [34]. There exist some other studies on turtle bycatch in the Central Eastern Pacific region, but for these observations either the fisheries did not target billfish (a category including swordfish) or they did not use shallow-set technology (depth of set is significantly associated with bycatch rate) [37, pp. 15–16; 38, p. 19].

The studies used to estimate the bycatch rate are summarized in Table 6. For all of these studies, the bycatch was reported by independent shipboard observers. The IATTC presentation does not break these bycatch figures down by species of sea turtle. We took the average of the bycatch rate across these 17 studies and conducted a bootstrap non-parametric analysis to estimate the probability distribution. The average bycatch rate is 2.3460 turtles/1000 hooks (95% CI 0.1110–10.1146 turtles/1000 hooks).

Combining the data and estimates developed in this paper, Table 7 estimates the net effect of the Hawaiian fishery closure on sea turtle interactions. To estimate the but-for turtle interactions in Hawaii, Table 7 uses the bycatch rates for the Hawaiian swordfish fishery from 1994 to 2002, before the technology regulation. This implicitly assumes that, had there been no fishery closure in 2001, the Hawaiian swordfish fishery would have continued to use the same technology it used previously.

The critical parameters driving our results are: comparative bycatch rates in Hawaii and the EPO (especially the probability distribution of the bycatch rate in the EPO); the catch of targeted fish per unit of effort (CPUE); and the estimated transferred catch. For the first critical parameters, the average bycatch rate in Hawaii would have to be more than ten times greater than it actually was in order for the fishery closure to have a net salutary effect on sea turtles, all else constant. For the second critical parameter, as CPUE increases more target fish are caught per unit of effort. As revealed in Table 7, if we use the upper confidence interval point for Hawaii and the EPO with the mean transferred catch, average weight of swordfish, and bycatch rate, the net effect on sea turtles

[9] An alternative method would be to derive each of these values from the experience of the Hawaiian fishery during the period after the partial re-opening of the Hawaiian fishery in 2004. When the fishery reopened in 2004, it did so under technology restrictions that required to use circle hooks and mackerel in place of squid bait, which resulted in a dramatic decline in the fishery's turtle bycatch rate [31].

[10] These CPUE values are estimates based on our inspection of the graphs printed in the IATTC presentation. The columns in the graph did not include labels indicating their values, so we had to estimate their values based on the heights of the columns compared to the scale on the y-axis.

Table 4
Sea turtle interactions variable names

Variable names	Description
Transferred swordfish catch (SSC)	The transferred swordfish catch is estimated in Section 5. For brevity, we estimate the net effect on sea turtles using only the most conservative estimate of the transferred swordfish catch.
Average weight of swordfish (AWS)	The average weight of a Hawaiian-caught swordfish from 1992 to 2000 (the years with the highest percentage of swordfish-dedicated trips) was 0.0780 mt/fish (95% CI 0.0726–0.0835 mt/fish) [32, pp. 3–46].
CPUE in Hawaii ($CPUE^h$)	The target-fish catch per unit effort in the Hawaiian swordfish fishery is well established and is based on a significant amount of data. For the period between 1994 and 2002, it was 13.29 fish/1000 hooks (95% CI 12.89–13.73 fish/1000 hooks), and for the period 2004–2006, it was 15.42 fish/1000 hooks (95% CI 15.09–15.78 fish/1000 hooks) [31].
CPUE in the Central Eastern Pacific region ($CPUE^C$)	The Inter-American Tropical Tuna Commission has conducted research on sea turtle bycatch in the shallow set fisheries in the Central Eastern Pacific. In addition to bycatch data, IATTC [35] collected data on target species CPUE. In the observed shallow-set fisheries, the target species were tuna, billfish, and shark.
Bycatch rate in Hawaii (B_yR^h)	For Hawaii, there are two bycatch rates that are relevant to a transferred-effects model. Before 2003, Hawaiian swordfish longliners typically used conventional fishing methods, in particular, J-hooks and squid bait. After the fishery reopened in 2004, due to regulations, the swordfish longliners were required to use circle hooks (18/0) and fish bait [31, p.1].
Bycatch rate in the Central Eastern Pacific (B_yR^C)	Outside of Hawaii, there is limited data on sea turtle bycatch rates. Many fisheries have collected no data at all, but a few have enough data to draw conclusions with sufficient confidence. The primary available information on bycatch in the Central Eastern Pacific is from a June 2006 presentation by the Inter-American Tropical Tuna Commission [35]. The study compares sea turtle bycatch rates in Tuna/Billfish/Shark shallow-set longline fisheries for two kinds of hooks (J-hooks and C16 circle hooks) in four countries: Ecuador, Panama, Costa Rica, and Peru.

Table 5
Bycatch rates for Hawaiian swordfish (shallow-set) longline fishery

	Total	Loggerhead	Leatherback	Olive Ridley	Green	Unknown
1994–2002	0.174[a]	0.130[b]	0.029[c]	0.008	0.004	0.003
2004–2006	0.019[d]	0.013[e]	0.005[f]	0.000	0.000	0.001

[a] 95% confidence interval: 0.150–0.199.
[b] 95% confidence interval: 0.109–0.152.
[c] 95% confidence interval: 0.020–0.038.
[d] 95% confidence interval: 0.013–0.025.
[e] 95% confidence interval: 0.008–0.019.
[f] 95% confidence interval: 0.002–0.008.

is 2018 mt, a figure that is 30% lower than reported in Table 7. If we use the lower confidence interval point for both Hawaii and the EPO, again with the same constant conditions, the net effect on sea turtles is 4336 mt, 50% higher than the result reported in Table 7. Finally, with regard to the estimated transferred catch, the results reported in Table 7 reveal that if the lower confidence interval point (868 mt), the net effect on sea turtles is 1561 mt, 40% lower than what is reported in Table 7. At the upper confidence interval point (transferred catch of 2337 mt), all else constant, the net effect on sea turtles is 4203 mt, 45% higher than the reported 2882 mt in Table 7.

These estimates of bycatch and mortality are conservative relative to those which appear elsewhere in the literature. This can be seen by a comparison of the resulting bycatch-to-catch (B_y/c) rates. NMFS [7] estimates B_y/c for Uruguay—only counting two species of turtle, leatherbacks and loggerheads—between 0.8 to 1.2 turtles per mt of swordfish caught. This is comparable to our B_y/c estimate for the Central Eastern Pacific of 2.0 turtles per mt of swordfish caught (95% CI 0.1–13.3). NMFS estimates B_y/c rates for Brazil (all species combined) of 23.2 turtle takes per mt of swordfish, more than an order of magnitude higher than our mean estimate. Bartram and Kaneko [5] estimate B_y/c rates for South Africa of 1.58 turtles per mt of swordfish, which is also comparable to our estimate. Bartram and Kaneko also estimate B_y/c rates for Costa Rica of 14.8 and 43.1 turtles per mt of mahi mahi, and they estimate B_y/c rates for Brazil of 4.8 and 30.9 turtles per mt of swordfish [5, p. 21].

6. Conclusions

When NMFS implemented the 2001 restriction of the Hawaiian swordfish-target fishery, it acknowledged the likelihood that the restriction would cause a transferred effect that might counteract the intended benefits to sea turtles. Our analysis confirms that a transferred effect did indeed occur, with an estimated annual market transfer effect of 1602 mt of swordfish of additional US imports. At the sample mean of the bootstrap distribution of bycatch rates, the transferred effect resulted in a net 2882 additional sea turtle interactions.

Does operating the Hawaiian fishery reduce global sea turtle interactions? Our analysis suggests that the conditions in the swordfish market exacerbate the occurrence of transferred effects. In particular, this is because the demand for swordfish, both in the US and abroad, is price inelastic, international swordfish fleets are flexible, and global swordfish trade is possible. These same conditions suggest, conversely, that an increase in Hawaiian catch is capable of displacing US fresh market imports. If this increased domestic catch is coupled with technology restrictions, for instance the use of fish bait and J-hooks, then it is possible that global sea turtle interactions can decline with a re-opening of the Hawaiian fishery, even if operation of the fishery leads to a net increase in global catch.

The available data from the period following re-opening of the Hawaiian shallow-set fishery under technology and effort limits in April 2004 supports this conclusion. We would expect, as a consequence of the partial lifting of the Hawaiian ban, that the US imports would decline, all else being equal. For recent years, there is insufficient data to do a complete analysis, but an analysis of the US imports data for 2005–2006 shows that there was a statistically significant decline in imports from several regions [1].

In addition to lowering turtle bycatch, there may be other benefits of maintaining the Hawaiian swordfish fishery. One benefit is transparency. Since 2004, the Hawaiian shallow-set fishery has had 100% federal observer coverage, which means that the validity of the bycatch data is high because there is no need to extrapolate bycatch rates from a sample. For most fisheries, bycatch rates must be estimated from very small samples, and for many there is little if any data. The presence of observers may also

Table 6
Reported bycatch rates for shallow-set longline fishing in the Central Eastern Pacific Region

Target species	Depth of set	Fishery	Year	Type of hook	Sets	Hooks	Observer coverage	Turtles caught in period	Bycatch rate (turtle interactions per 1000 hooks)
Tuna/Billfish/Shark	Shallow	Peru (South)	2005	J	391	916,191			0.0[a]
Tuna/Billfish/Shark	Shallow	Peru (South)	2005	Circle					0.3
Tuna/Billfish/Shark	Shallow	Peru (Central)	2005	J					0.2
Tuna/Billfish/Shark	Shallow	Peru (Central)	2005	Circle					0.1
Tuna/Billfish/Shark	Shallow	Peru (North)	2005	J					3.6
Tuna/Billfish/Shark	Shallow	Peru (North)	2005	Circle					2.6
Tuna/Billfish/Shark	Shallow	Ecuador	2004	J					1.3
Tuna/Billfish/Shark	Shallow	Ecuador	2004	Circle					0.8
Tuna/Billfish/Shark	Shallow	Ecuador	2005	J					3.4
Tuna/Billfish/Shark	Shallow	Ecuador	2005	Circle					1.4
Tuna/Billfish/Shark	Shallow	Panama	2005	J					1.8
Tuna/Billfish/Shark	Shallow	Panama	2005	Circle					0.7
Tuna/Billfish/Shark	Shallow	Costa Rica	2004	J					2.1
Tuna/Billfish/Shark	Shallow	Costa Rica	2004	Circle					1.7
Tuna/Billfish/Shark	Shallow	Costa Rica	2005	J					2.3
Tuna/Billfish/Shark	Shallow	Costa Rica	2005	Circle					0.7
Billfish/Shark/Mahi-mahi	Shallow (25–90 m)	Costa Rica	1997		9	3554		60	16.882[b]

[a] Numbers are approximate because they are estimated based on a graph. Also, bycatch rates are not based on a random sample of sets [35, p. 2].
[b] Arauz et al. [34, p. 62].

Table 7
Net effect of the Hawaiian fishery closure on sea turtle interactions (CPUE and bycatch rate in Hawaii based on pre-closure rates)

	Mean	95% CI lower limit	95% CI upper limit
1. But-for Hawaiian turtle interactions			
Transferred swordfish catch (mt)	1602.15	867.96	2336.97
[divided by]			
Avg. weight of swordfish (mt)	0.0780	0.0726	0.0835
[divided by]			
CPUE in Hawaii (fish/1000 hooks)	13.29	12.89	13.73
[multiplied by]			
Bycatch rate in Hawaii (turtles/1000 hooks)	0.1740	0.1500	0.1990
But-for Hawaiian turtle interactions	268.86	113.56	496.97
2. Transferred effect due to increased catch in the Central Eastern Pacific			
Transferred swordfish catch (mt)	1602.15	867.96	2336.97
[divided by]			
Avg. Weight of swordfish (mt)	0.0780	0.0726	0.0835
[divided by]			
CPUE in Central Eastern Pacific (fish/1000 hooks)	15.29	10.44	21.15
[multiplied by]			
Bycatch rate in Central Eastern Pacific (turtles/1000 hooks)	2.3460	0.1110	10.1146
Transferred effect	3150.51	54.54	31,177.39
3. Net effect on sea turtles			
Transferred effect (turtles)	3150.51	54.54	31,177.39
[minus]			
But-for Hawaiian turtle interactions (turtles)	268.86	113.56	496.97
Net effect on sea turtles (turtles)	2881.65	−59.02	30,680.42

reduce the actual bycatch and post-hook mortality since fishers would be more likely to follow best practices for preventing turtle bycatch and for releasing hooked turtles. In addition, there may be demonstration effects: Maintaining well-regulated fisheries may have positive transferred effects. Well-regulated fisheries may demonstrate to unregulated fisheries that practices such as the use of circle hooks and fish bait can reduce turtle bycatch while maintaining profitability, which might lead to more widespread use of these practices.

Acknowledgments

The authors thank the Hawaii Longline Association for funding this research and Jeff Leppo for his useful comments. The authors also thank Milani Chaloupka, Rick Deriso, Eric Gilman, Martin Hall, Michael Hinton, John Kaneko, Irene Kinan and Steve Koplin, for sharing information, helping interpret available data and reviewing initial drafts of this manuscript.

Appendix A

Variable definitions, data sources and summary statistics are shown in Tables A1 and A2.

Table A1
Variable definitions and data sources

Variable name	Description	Sources
$Q_{i,t}^{D,F}$	Fresh swordfish purchased. Measured as the weight of domestic production+fresh imports−fresh exports. Domestic production is not separated into fresh and frozen. Imported steaks, fillets and whole fresh swordfish reported in the trade data were aggregated. Evidence suggests domestic swordfish catch is marketed entirely as fresh product. Thousands of pounds	National Oceanic and Atmospheric Administration (NOAA) Office of Science and Technology (OST) Fisheries Statistics Division. "Commercial Fisheries: Commercial Fisheries Landings—Annual." http://www.st.nmfs.gov/st1/commercial/landings/annual_landings.html *Personal communication from the National Marine Fisheries Service, Fisheries Statistics Division, Silver Spring, MD* [**A**] NOAA OST Fisheries Statistics Division. "US Foreign Trade: Product by Country/Association" http://www.st.nmfs.gov/st1/trade/annual_data/TradeDataAnnualProductCountry.html *Personal communication from the National Marine Fisheries Service, Fisheries Statistics Division, Silver Spring, MD* [**B**]
$Q_{i,t}^{D,Z}$ [a]	Frozen swordfish purchased. Measured as frozen imports−frozen exports. Imported steaks, fillets and whole frozen swordfish reported in the trade data were aggregated. Thousands of pounds	[**B**]
$P_{i,t}^{F,SWO}$ [b]	Average annual landed price of fresh swordfish imported into the US. Time-series data on landed price levels of domestic product are not readily available. Landed prices were adjusted to constant 2000 dollars using an index of ex-vessel swordfish prices. $ per pound	[**B**]; NOAA National Marine Fisheries Service. 2005. "Fisheries of the United States" http://www.st.nmfs.gov/st1/fus/fus05/index.html [**C**]
$P_{i,t}^{Z,SWO}$	Annual landed price of frozen swordfish imported into the US. Landed prices were adjusted to constant 2000 dollars using an index of ex-vessel swordfish prices. $ per pound	[**B**], [**C**]
$P_{j,t}^{F,SAL}$	Annual landed price of fresh salmon imported into the US landed prices were adjusted to constant 2000 dollars using an index of ex-vessel salmon prices. Import prices were used as the price signal for landed fresh salmon prices in the US. $ per pound	[**B**], [**C**]
$P_{j,t}^{Z,SAL}$	Annual landed price of frozen salmon imported into the US. Landed prices were adjusted to constant 2000 dollars using an index of ex-vessel salmon prices. Import prices were used as the price signal for landed frozen salmon prices in the US. $ per pound	[**B**], [**C**]
$I_{i,t}^{US}$	Annual US GDP reported in billions of chained 2000 dollars. This variable represents income and was converted to per capita by dividing annual real GDP by the US population as of July 1 in each year. $Billion per million persons	US Federal Reserve Bank "Economic Data," St. Louis. http://www.economagic.com
FDA	Dummy variable taking on a value of 1 during 2001–2005 (0 otherwise) to control for the FDA announcements regarding mercury levels in swordfish.	
$Q_{i,t}^{S,F,EPO}$	Fresh swordfish supplied by nations in the eastern Pacific Ocean region. Measured as the level of US fresh swordfish imports sourced from nations near/in the eastern Pacific Ocean. Imported steaks, fillets and whole fresh swordfish reported in the trade data were aggregated. Thousands of pounds	[**B**]
$Q_{i,t}^{S,F,CAR}$	Fresh swordfish supplied by nations in the Caribbean Ocean region. Measured as the level of US fresh swordfish imports sourced from nations near/in the Caribbean Ocean. Imported steaks, fillets and whole fresh swordfish reported in the trade data were aggregated. Thousands of pounds	[**B**]
$Q_{i,t}^{S,F,NWPAC}$	Fresh swordfish supplied by nations in the northwest Pacific Ocean region. Measured as the level of US fresh swordfish imports sourced from nations near/in the northwest Pacific Ocean. Imported steaks, fillets and whole fresh swordfish reported in the trade data were aggregated. Thousands of pounds	[**B**]
$Q_{i,t}^{S,F,SAATL}$	Fresh swordfish supplied by nations in the South America Atlantic Ocean region. Measured as the level of US fresh swordfish imports sourced from nations near/in the South America Atlantic Ocean. Imported steaks, fillets and whole fresh swordfish reported in the trade data were aggregated. Thousands of pounds	[**B**]

Table A1 (*continued*)

Variable name	Description	Sources
$Q_{i,t}^{S,F,SAPAC}$	Fresh swordfish supplied by nations in the South America Pacific Ocean region. Measured as the level of US fresh swordfish imports sourced from nations near/in the South America Pacific Ocean. Imported steaks, fillets and whole fresh swordfish reported in the trade data were aggregated. Thousands of pounds	[**B**]
$Q_{i,t}^{S,F,SWPAC}$	Fresh swordfish supplied by nations in the southwest Pacific Ocean region. Measured as the level of US fresh swordfish imports sourced from nations near/in the southwest Pacific Ocean. Imported steaks, fillets and whole fresh swordfish reported in the trade data were aggregated. Thousands of pounds	[**B**]
$P_{i,t}^{F,EPO}$	Current, landed price of fresh swordfish supplied from nations in the eastern Pacific Ocean region. Measured by dividing total value of fresh swordfish imports by the weight of fresh swordfish imports from nations near/in the eastern Pacific Ocean region. $ per pound	[**B**], [**C**]
$P_{i,t}^{F,CAR}$	Current, landed price of fresh swordfish supplied from nations in the Caribbean Ocean region. Measured by dividing total value of fresh swordfish imports by the weight of fresh swordfish imports from nations near/in the Caribbean Ocean region. $ per pound	**[B]**, [**C**]
$P_{i,t}^{F,NWPAC}$	Current, landed price of fresh swordfish supplied from nations in the northwest Pacific Ocean region. Measured by dividing total value of fresh swordfish imports by the weight of fresh swordfish imports from nations near/in the northwest Pacific Ocean region. $ per pound	[**B**], [**C**]
$P_{i,t}^{F,SAATL}$	Current, landed price of fresh swordfish supplied from nations in the South America Atlantic Ocean region. Measured by dividing total value of fresh swordfish imports by the weight of fresh swordfish imports from nations near/in the South America Atlantic Ocean region. $ per pound	[**B**], [**C**]
$P_{i,t}^{F,SAPAC}$	Current, landed price of fresh swordfish supplied from nations in the South America Pacific Ocean region. Measured by dividing total value of fresh swordfish imports by the weight of fresh swordfish imports from nations near/in the South America Pacific Ocean region. $ per pound	**[B]**, [**C**]
$P_{i,t}^{F,SWPAC}$	Current, landed price of fresh swordfish supplied from nations in the southwest Pacific Ocean region. Measured by dividing total value of fresh swordfish imports by the weight of fresh swordfish imports from nations near/in the southwest Pacific Ocean region. $ per pound	[**B**], [**C**]
$Q_{i,t}^{S,Z}$	Frozen swordfish imported from all regions in the current year. Measured as the weight of frozen swordfish imports. The entire domestic catch is marketed fresh; therefore the quantity of frozen swordfish supplied is sourced entirely through imports. Imported steaks, fillets and whole frozen swordfish reported in the trade data were aggregated. Thousands of pounds	[**B**]
$P_{i,t}^{S,Z}$	Annual landed price of frozen swordfish imported into the US during the current year. Landed prices were adjusted to constant 2000 dollars using an index of ex-vessel swordfish prices. $ per pound	[**B**], [**C**]
$Q_{i,t-1}^{S,Z}$	Frozen swordfish imported from all regions in during the prior year. Measured as the weight of frozen swordfish imports. The entire domestic catch is marketed fresh; therefore the quantity of frozen swordfish supplied is sourced entirely through imports. Imported steaks, fillets and whole frozen swordfish reported in the trade data were aggregated. Thousands of pounds	[**B**]
F_{t-1}^{EPO}	A proxy for production flexibility of the countries in fishing within the Central Eastern Pacific Ocean region. Flex was computed as follows: Each country that sourced catch from the Central Eastern Pacific Ocean region at any point during 1990–2005 were identified within the data. The total annual catch of those countries in each ocean region was then computed, and the percentage of the total catch that was sourced from the Central Eastern Pacific Ocean region was then calculated. The first difference of the percentage was taken to represent the annual change.	FAO Fisheries and Aquaculture Information and Statistics Service. 2007. Total production 1950–2005. FISHSTAT Plus-Universal software for fishery statistical time series [online or CD-ROM]. Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp [**D**]
F_{t-1}^{CAR}	[Same as described for F_{t-1}^{EPO}, but for the Caribbean Ocean region.]	[**D**]
F_{t-1}^{NWPAC}	[Same as described for F_{t-1}^{EPO}, but for the Northwest Pacific Ocean region.]	[**D**]

Table A1 (*continued*)

Variable name	Description	Sources
F_{t-1}^{SAATL}	[Same as described for F_{t-1}^{EPO}, but for the South America Atlantic Ocean region.]	[**D**]
F_{t-1}^{SAPAC}	[Same as described for F_{t-1}^{EPO}, but for the South America Pacific Ocean region.]	[**D**]
F_{t-1}^{SWPAC}	[Same as described forF_{t-1}^{EPO}, but for the Southwest Pacific Ocean region.]	[**D**]
$Q_{i,t}^{S,F,ROW}$	Pre-determined fresh swordfish supply to the US market sourced from the Africa, Southeast Asia, Indian Ocean and Europe, collectively "Rest-of-world." The US did not import fresh swordfish from these four regions in each year during 1990–2005. Measured as the level of US fresh swordfish imports sourced from nations in these four regions.	[**C**]
$Y_{i,t}^{F,DOM}$	Pre-determined fresh swordfish supply to the US market sourced from domestic production. Measured as annual US commercial swordfish landings computed from state-level data.	National Oceanic and Atmospheric Administration (NOAA) Office of Science and Technology (OST) Fisheries Statistics Division. "Commercial Fisheries: Commercial Fisheries Landings—by State; Annual." http://www.st.nmfs.gov/st1/commercial/landings/annual_landings.html *Personal communication from the National Marine Fisheries Service, Fisheries Statistics Division, Silver Spring, MD* [**E**]
$Q_{i,t}^{S,F,PD}$	Total pre-determined supply of fresh swordfish to the US market. Measured as: $Q_{i,t}^{S,F,ROW}+Y_{i,t}^{F,DOM}$	[**C**], [**E**]

[a] As a result of a reclassification of frozen imports in the trade data, reported annual frozen swordfish imports were inflated using the results from a simple linear regression of quantity imported on time.

[b] In all cases, fresh and frozen, import prices were computed as the weighted average of steaks, fillets and whole swordfish. The same procedure was followed for computing the price of salmon.

Table A2
Summary statistics

Stats	Qd_f	Qd_z	Qs_f_epo	Qs_f_car	Qs_f_nwpac	Qs_f_saatl	Qs_f_sapac	Qs_f_swpac	Qs_z	Qs_z1	Qs_f_PD
N	16	16	16	16	16	16	16	16	16	15	16
Mean	29580.45	14549.97	3760.04	587.59	2252.48	2798.36	3629.47	1406.19	14549.97	14986.78	15146.32
sd	5460.70	5529.22	2169.38	313.38	635.65	1451.80	2375.45	1242.97	5529.22	5430.02	4660.21
Max	37020.59	26300.00	8301.06	1235.29	3869.27	5001.95	9141.67	3276.90	26300.00	26300.00	23943.24
Min	20873.87	7997.81	791.56	167.81	1296.10	975.33	1620.21	12.22	7997.81	8818.23	7401.01
Stats	Pswo_fl	Psal_fl	Ps_f_epo	Ps_f_car	Ps_f_nwpac	Ps_f_saatl	Ps_f_sopac	Ps_z	Ps_f_swpac	Pswo_z2	Psal_z2
N	16	16	16	16	16	16	16	16	16	16	16
Mean	3.23	2.43	2.89	3.63	4.30	1.88	3.72	2.75	2.93	2.75	2.50
sd	0.73	0.69	0.58	0.49	0.96	0.34	0.73	0.87	0.69	0.87	0.74
Max	4.46	4.14	4.16	4.63	5.79	2.58	5.12	4.49	4.54	4.49	4.09
Min	2.12	1.36	2.06	2.98	2.84	1.30	2.43	1.49	1.98	1.49	1.24
Stats	Ps_f_sapac	Ps_z	Ps_f_swpac	GDP_pc	flex_epo1	flex_car1	flex_nwpac1	flex_sapac1	flex_swpac1	flex_saatl1	
N	16	16	16	16	15	15	15	15	15	15	
Mean	3.72	2.75	2.93	32.2934	0.00120	−0.00209	−0.00061	0.00074	0.00043	0.00523	
sd	0.73	0.87	0.69	3.10022	0.03270	0.01393	0.04972	0.04370	0.01081	0.03080	
Max	5.12	4.49	4.54	37.25084	0.05222	0.02049	0.08876	0.10235	0.01820	0.07021	
Min	2.43	1.49	1.98	28.00986	−0.05815	−0.03303	−0.07405	−0.07383	−0.02095	−0.03318	

Appendix B. Bootstrap analysis of transferred swordfish supply

We performed non-parametric bootstrap simulations for four of the inputs to the bycatch-estimation equation: turtle bycatch rates in the Eastern Pacific, transferred swordfish catch, target fish CPUE, and swordfish weight. The purpose of the simulations was to estimate the characteristics of the population from which these samples were derived, without assuming a particular distribution. On the basis of each simulation, we estimated four summary statistics: the upper and lower 95% confidence interval limits, the mean and the median. In all four cases, 1000 samples were drawn. The sample sizes were: 17 observations for the ByCatch rate, 12 observations for the Target Fish CPUE, 9 observations for the Swordfish Weight, and 4 observations for the Transferred Swordfish Catch. The graphs below depict the distributions of the estimated means for turtle bycatch rates in the Eastern Pacific, target fish CPUE, and swordfish weight. The histogram for the Transferred Swordfish Catch is not displayed here due to its relatively small sample size resulting in a discrete, not continuous, distribution of the mean (Fig. B1).

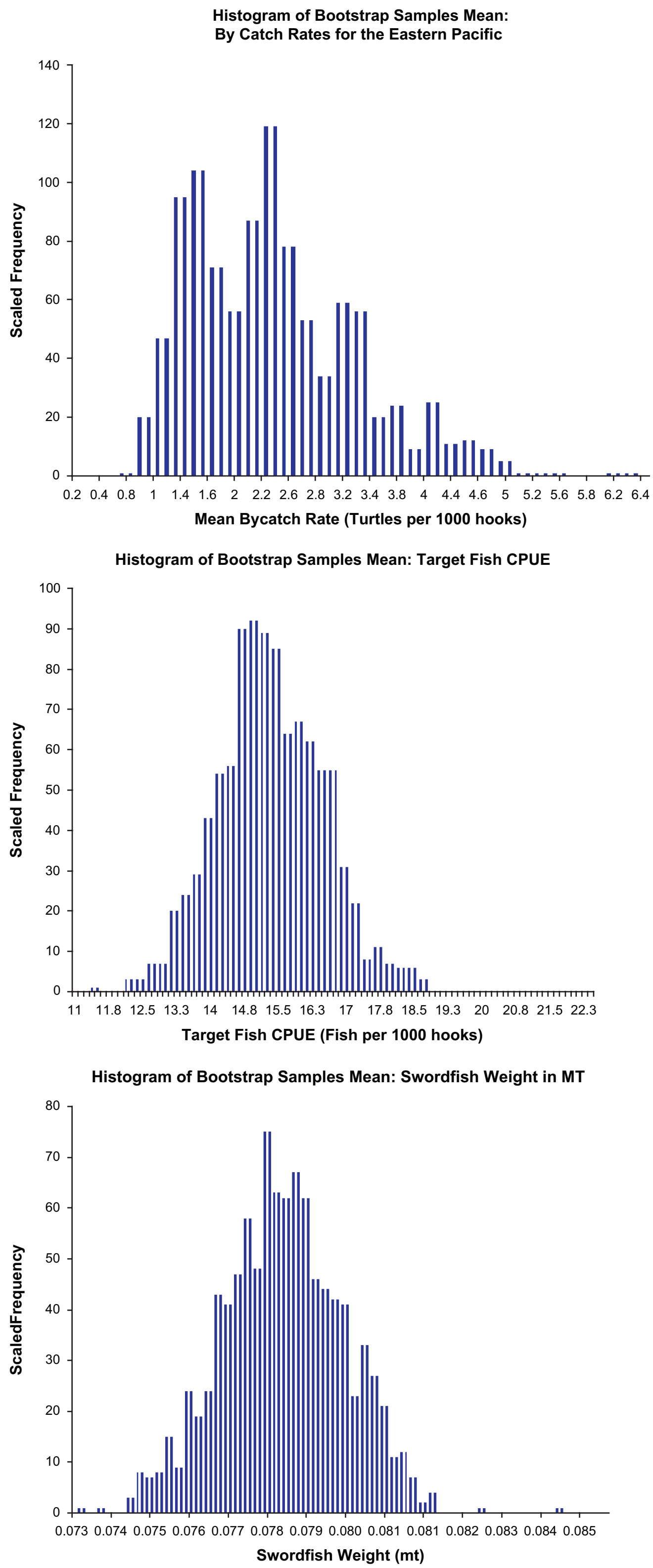

Fig. B1

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