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Shark Hunting: International Trade and the Imminent Extinction of Heterogeneous Species*

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Abstract

This paper examines the unprecedented decimation of sharks. We develop a Ricardian Gordon-Schaefer model with a continuum of heterogeneous species which are subject to combined harvesting and perfect substitutability in consumption. The model implies that slow-growing species, surviving in autarky, will be driven to extinction in an open trade regime. In the empirical analysis, we show that the model is in line with observations of shark biology and the international shark market. In particular, the likelihood of extinction turns out to be significantly greater for shark species which are part of trade in shark fins and exhibit low intrinsic growth. (JEL F14, F18, Q27, Q57)

Keywords: Sharks, Trade and Renewable Resources, Biodiversity

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1 Introduction

Sharks are extremely fast and strong hunters; they can be life-threatening for humans. Pictures of open-mouthed great whites in the Internet or in children's books witness the danger of this animal; a shark's sudden appearance in movies typically petrifies the audience. Despite recent demonstrations that sharks are mostly shy and peaceful animals when exposed to humans,[1] the widespread fear of sharks may explain why their recent decimation by the most dangerous hunter on earth – the human being – has largely been ignored by the public. Worm et al. (2013) report that 100 million sharks or 6-8% of the world shark population are killed every year, while individual species have been more severely depleted. The stock of the hammerhead shark, for example, fell by 89% between 1986 and 2000 in the North Atlantic (Baum et al. (2003)) and the catch rate of the whitetip shark in the Pacific Ocean decreased by 90% from 1996 to 2009 (Clarke et al. (2013)).

This paper identifies the economic forces driving shark decimation, and evaluates the relative extinction risk of shark species. We argue that the combination of open access, international trade and high demand in Asian economies forms the basis of the observed depletion of sharks. Our main argument is that the heterogeneity among shark species regarding their reproduction, together with combined harvesting and close substitutability in consumption, puts slow-growing shark species at an imminent risk of extinction. We use theory and data on a wide range of heterogeneous shark species to make our case.

Our investigation is based on three ingredients. First, we build a Ricardian Gordon-Schaefer model with a continuum of heterogeneous species to study the effect of international trade and differences in preferences on the stock of a resource.[2] We find that extinction of relatively slow-growing species due to international trade is likely in this set-up. As profit-maximizing hunters of sharks take into account the *total* stock productivity in their decision to harvest, a reduction in the stock of slow-growing species hardly affects productivity and resource prices.

Second, using recent trade data as well as fin-to-body weight ratios we provide evidence that shark fin trade is the most important driver of the decimation of the worldwide shark population, with most fins being exported to fast growing Asian economies. Moreover, even though sharks are composed of, in many respect, very heterogeneous species, they are hardly distinguished neither in harvesting nor in consumption – most of the sharks being consumed in form of the so-called "shark fin soup".

Third, we use data on the heterogeneity of the rebound potential of different shark species and their extinction risk, approximated by their degree of vulnerability reported by the Red List of the International Union for Conservation of Nature (IUCN), to test the model's predictions regarding extinction. We find that shark species with a relatively low rebound potential and which are part of shark fin trade do face a significantly higher risk of extinction.

[1] See http://www.sharkwater.com, last accessed 24.06.2015. The relatively low fatality rates of people-shark encounters statistically support this perspective; see http://www.sharkattackfile.net, last accessed 05.01.2015.

[2] The model uses Brander and Taylor (1997a,b) as a foundation.

The rapid depletion of sharks has been studied by a number of marine biologists.[3] Myers et al. (2007) emphasize the unanticipated consequences to oceanic ecosystems if apex predators become nearly or completely extinct. While most sharks were unprotected until recently, the cruel practice of shark finning – where fisherman cut off the shark's valuable fins and discard its (sometimes still living) body into the ocean – led governments to implement finning regulations.[4] Moreover, some shark species are now listed in Appendix II of the Convention on International Trade in Endangered Species (CITES) which implies that exporters are required to obtain permits to export fins.

There is a long history of renewable resource overuse. Pauly et al. (2002) argue from historical accounts that unsustainable fisheries practices seem to be the rule rather than the exception. Well-known examples from the last century include cod stocks in the North Atlantic in the nineteen-nineties (Hutchings (2000)) and the Peruvian anchoveta in the nineteen-seventies (Pauly et al. (1998)). Progress in hunting technology has played an important role in other cases, such as the decimation of the Eastern Arctic bowhead over an extended period from 1600 to 1900 (Allen and Keay (2004)). Branch et al. (2013) recently emphasized that the harvesting of the severely depleted Antarctic blue whale continued as a result of hunting the more abundant fin whale species – a scenario which turns out to be important in the shark case.

The fact that international trade may amplify environmental problems when resources are subject to open access has recently been studied by trade economists.[5] Brander and Taylor (1997b) emphasize that trade may also allow a resource to recuperate if trade patterns reverse as a resource good becomes overused in a country. The excessive shark hunting shows similarities to the mass killing of the North American buffalo between 1871 and 1883 from 10 to 15 million buffalo down to a mere 100. Taylor (2011) reveals that this was caused by a sudden increase in European demand for buffalo hides due to a technological innovation in the tanning process in England and Germany. His study implies that international trade may lead to an extremely fast depletion of natural resources, to which a government – in his case the U.S. government – may hardly have sufficient time to react.

Our paper contributes to this literature by focusing on the fate of heterogeneous species, in general, and providing a detailed economic analysis of the shark depletion, in particular – both of which have not been studied in economics, according to our knowledge. The paper also contributes to the literature on renewable resource collapse. Taylor (2009) identifies three preconditions for environmental crises: weak resource governance, feedback effects in the environmental ecosystem, and threshold levels below which resources cannot recuperate. We add that combined harvesting of multiple, heterogeneous species which are close substitutes in consumption constitutes a further important aspect.

[3]See, for example, Baum et al. (2003), Clarke et al. (2007), or Worm et al. (2013).

[4]The U.S. introduced the Shark Finning Prohibition Act of 2000 and Shark Conservation Act of 2010. The EU first introduced fin-to-body weight ratios in 2003 with Regulation (EC) 1185/2003; in 2012, the European Parliament voted for a complete shark finning ban, allowing fishers to only land fins with bodies of sharks attached to them.

[5]See, for example, Chichilnisky (1994), Brander and Taylor (1997a,b) or Copeland and Taylor (2009).

The remainder of the paper is structured as follows: Section 2 provides relevant facts regarding shark biology, fisheries and populations. Section 3 presents the model of shark hunting to study the combined effects of domestic demand, international trade and the existence of a multiple heterogeneous species. Section 4 focuses on the empirical analysis of the shark case. Section 5 concludes.

2 Sharks and Shark Hunting

In this section, we provide key elements of (i) shark biology, (ii) shark consumption and production as well as (iii) international trade and (iv) shark stocks that are relevant for the subsequent theoretical and empirical analyses.

2.1 Shark Biology

Sharks are part of the class of chondrichthyes, together with rays and the small group of chimaeras, and are known to have lived 400 million years ago, long before dinosaurs even began to exist (Klimley (2013)). They are a so-called superorder of more than 500 species (Campagno et al. (2005)) which differ in their habitat, size and seemingly every possible characteristic. Some shark species predominantly live in coastal areas, some move around in the open ocean, some species dive down to abyssal depths, and some even move in fresh water. When adding all the habitats of sharks (as reported in Campagno et al. (2005)), the shark's geographic distribution spans all of our planet's oceans with the typical habitat, however, being near-shore coastal areas.

Shark species show a strong variation in their life-history characteristics (Campagno et al. (2005)). The Rhincodon typus (whale shark) can reach a length of more than 20 meters, while small sharks such as the Apristurus sibogae (pale catshark) or the Etmopterus virens (green lanternshark) do not grow much longer than 20 centimeters. The age of maturity fluctuates between 1 year (Australian sharpnose shark) and 20 to 25 years (piked dogfish). Sharks' life expectancy spans range widely: Some species are known to live for only 5 years according to Dulvy and Forrest (2010), while Hamady et al. (2014) identified a white shark that was 73 years old. Some shark species lay eggs, others give birth to live young (Dulvy and Forrest (2010)). Shark species do, however, share some common characteristics, such as their cartilaginous skeleton and (rather obviously, but important for our further analysis) their fins: All shark species have at least one dorsal and a caudal fin.

Large sharks generally have a slow reproduction rate, resulting from their slow body growth, late maturation and few progeny. Such species are often located in stable habitats and exhibit intrinsic, density-dependent mortality. Clarke et al. (2007) thus emphasize that large sharks' survival strategies did not develop under situations with high natural mortality, as most of these species are apex predators that face no natural enemy. Consequently, Dulvy and Forrest (2010) conclude that the shark's life-history characteristics of sexual maturation and fertility make sharks particularly vulnerable to fishing pressures.

2.2 Shark Consumption and Production

The historical literature refers to shark meat being consumed in the fourth century and being part of the traditional diet in Asia, Africa and Latin America (see Vannuccini (1999)). Vannuccini (1999) also reports that in some countries, shark meat is marketed under a different name, e.g., the "Squalus acanthias" which is sold in Germany as "Seeaal" or as "Schillerlocken". In some places, shark meat is sold in fish and chips under the name of "Flake" or "Rock Salmon". The market value of shark meat is low compared to other types of fish meat (e.g., tuna or swordfish).

Clarke et al. (2007) investigate the origins of shark fin consumption in China. They note that shark fins were traditionally served to emperors during the Ming dynasty (1368-1644 AD). Due to policies of cultural reform in the Mao era (1949-1976), shark fin consumption was discouraged. In the beginning of the Deng Xiaoping era (1979-1997), shark fins were, again, accepted, but simply too expensive for the majority of the Chinese population. Today, shark fin soups have become a luxury product in China and some other countries, served especially at weddings.

Whereas shark products were long supplied by small-scale artisanal fisheries, sharks are now caught in industrial fisheries and as bycatch in pelagic fisheries that target tunas. Dulvy and Forrest (2010) stress that the techniques for catching sharks are mainly bottom- and pelagic trawling and longlining. Due to the large price difference between meat and fins – NMFS (2009) reports the respective U.S.-export prices of 2 US$ and 94 US$ per kg for 2007 – finning the sharks and discarding the body became a widespread practice.

According to the Food and Agriculture Organization (FAO), aggregate landings of Chondrichthyans in (metric) tonnes (sharks, rays and chimaeras) for the world as a whole more than tripled between 1950 and 2000, slightly decreasing thereafter and reaching 771,795 tonnes in 2013.[6] An analysis of the structure shows that a broad group of countries are involved in production. In 2013, Indonesia (15% of total chondrichthyan landings), Spain (14%), and India (9%) were the leading shark hunting countries, followed by Mexico (5%), the United States (5%), Taiwan (4%), Argentina (3%), Malaysia (3%), and Nigeria (3%). According to Worm et al. (2013) approximately half of these catches are sharks.

It is, however, argued that these numbers largely underestimate the true extent of shark catches and mortality. Camhi et al. (2008, p. 168), for example, estimate that these numbers only reflect half of the actual catches, mainly because of voluntary reporting and "deliberate under-reporting". Also note that FAO data are based on the weight of *landed* sharks and do not include discards at sea. Assuming that the practice of finning increased during the period of observation, the growth in the number of sharks killed would be much higher. Worm et al. (2013) thus estimate a total mortality of sharks due to fishing of twice as much, i.e., 1.45 million tonnes per year, corresponding to about 100 million sharks.

[6] Fishstat Database: Capture Production. http://www.fao.org/fishery/statistics/en, downloaded 1.12.2014.

2.3 Shark Trade

According to FAO data, world-wide shark imports (including shark meat, fins and oil) increased from 24,000 tonnes in 1976 to 120'000 tonnes in 2011.[7] In the same period, global exports are reported to have increased by much more (a factor of 8). The weight of all imported shark fins increased from 3,710 (1976) to 17,154 (2011) tonnes. From 2012 onwards, data for shark imports are available in the UN Comtrade database, implying that worldwide imports of shark products in tonnes dropped by 11% from 2012 to 2013.[8]

UN Comtrade data imply that Singapore and China (mainly Hong Kong) are by far the most important countries for exported and imported shark fins in 2013, followed by a large number of small exporters and importers. For shark meat (including frozen fins), Spain and Uruguay were among the largest exporters and importers in terms of weight in 2013, with Brazil being the largest importer. Thus, in contrast to the highly concentrated fin market, a large number of countries are involved in imports and exports of shark meat.

While shark fins have a relatively small share in international trade of shark products in terms of weight, their monetary value accounts for the major share. The FAO reports a share of 79% (58%) in the year 2000 (2011), UN Comtrade a share of 45% in 2012 (excluding frozen fins). In an attempt to translate trade figures into the number of killed sharks, Clarke et al. (2006) uses data from shark fin auctions in Hong Kong, (then) the global center of the shark fin trade. They estimate that between 26 and 73 million sharks are caught for shark fin trade per year.

2.4 Shark Stocks

Baum et al. (2003) analyze logbook data of the North Atlantic longline fleet. They estimate that (with one exception, the Mako Shark) all considered shark species declined in abundance by more than 50% during the investigated time periods. Baum and Myers (2004) compare shark stocks in the Gulf of Mexico in the late 1990s with those in the 1950s and notice declines of 99% for the oceanic whitetip and 90% for the silky shark. Ferretti et al. (2008) find a decline in the stocks of large sharks in the Mediterranean Sea from 96% to 99.99% and conclude that large predatory sharks may become extinct. Clarke et al. (2013) analyze a dataset collected by on-board observers, recording shark catches in the Pacific Ocean between 1995 and 2010. They find that the catch rate considerably decreased for the blue shark and the oceanic whitetip shark.

All the consulted studies thus imply that shark stocks are in strong decline due to fishing pressures.[9] Worm et al. (2013) conclude that for 48% of fished shark populations, the exploitation rate was above their potential rebound rate. Consequently, the recent declines in production and trade data reported above are likely to be an outcome of the declining shark stocks. By now, several shark species are on the Red List of IUCN. Out of the 473 reported species, 211 are "data deficient" and therefore not classified. When considering species with

[7] Fishstat Database: Fisheries Commodity Production and Trade Statistics. http://www.fao.org/fishery/statistics/en, downloaded 26.11.2014.

[8] Downloaded 16.03.2015.

[9] See also Dulvy and Forrest (2010) for a survey of studies on shark population declines.

available data, more than one quarter of these species are classified as being critically endangered, endangered, or vulnerable. Again, the heterogeneity among shark species seems to be very important and will, therefore, be taken into account in our further analysis.

3 The Model

We establish a Ricardian Gordon-Schaefer model with a continuum of species, using Brander and Taylor (1997a,b) as a foundation. The species are jointly harvested and perfect substitutes in consumption. We start by describing the growth and the harvest of the multi-species, open-access renewable resource. After deriving the autarky equilibrium, we highlight the effects of international trade on resource depletion and the range of surviving species, assuming that countries differ in their demand for the resource. The final subsection discusses the results regarding the extinction of species.

3.1 The Resource

The stock of a given species z in a country at time t is denoted by $s(z,t)$. The natural growth of the resource is $g(s(z,t))$; the harvest or hunting of it is denoted by $h(z,t)$. The change in the stock of species z thus equals

$$ds(z,t)/dt = g(s(z,t)) - h(z,t). \tag{1}$$

We index species on an interval $[0, \tilde{z}]$ in accordance with their decreasing intrinsic growth rate $r(z)$, i.e., $r'(z) < 0$.[10] The natural growth of each species is given by the logistic function that exhibits compensatory growth:

$$g(z) = r(z)s(z)(1 - s(z)/k), \tag{2}$$

where k denotes the carrying capacity of the stock. When s reaches k, the stock stops growing. If, in contrast, s is very small relative to the carrying capacity, the stock grows approximately proportionally to s at the intrinsic or uncongested growth rate $r(z)$; i.e., $g(s)/s(z) \approx r(z)$. The larger the stock, the more congested and therefore the lower is the growth rate $g(s)/s(z)$. Equation (2) thus implies that the increment of each species' stock first rises with the stock, reaches a unique maximum at $s_{MSY} = k/2$ (i.e., the stock which gives rise to the "maximum sustainable yield" (h_{MSY})), and then falls until it reaches zero at $s(z) = k$.[11] The total stock of all species in a country at time t is denoted by S:

$$S = \int_0^{\tilde{z}} s(z)dz. \tag{3}$$

[10] From now on, the time index is dropped for notational convenience.

[11] The main feature of the logistic growth function is compensatory growth, meaning that the stock of a species grows at a faster rate when the stock size declines. Biologists also applied the logistic growth function to analyze the dynamics of shark populations (see e.g. Dulvy and Forrest (2010) or Klimley (2013)).

3.2 The Hunting

To determine the share of labour in harvesting in autarky, suppose a country producing two goods, i.e., quantities of a manufacturing (outside) good, M, and of the harvest good, H (all species of sharks). L denotes the total population, while L_M and L_H equals the labour force in the manufacturing and the harvesting sector, respectively. Labour is assumed to be the only input to the manufacturing sector. With a constant labour coefficient, a_{LM}, the manufacturing output equals $M = (1/a_{LM})L_M$. Given the price of the manufacturing good, p_M, free entry ensures that the wage rate equals the value of marginal product of labour; i.e., $w = (1/a_{LM})p_M$.

Analogously, harvesting is a function of labour productivity and the amount of labour used in this sector; i.e., $H = (1/a_{LH}(S))L_H$. Note that the labour coefficient depends on the total stock of the resource (S), as both labour and the total resource stocks are inputs to harvesting. As it is easier to catch sharks when the stock is large, we assume that a_{LH} negatively depends on S. More precisely, we assume that $a_{LH} = 1/(\alpha S)$, where $\alpha > 0$ describes the fishery technology, e.g., how many sharks can be hunted per unit of labour at a given stock. This leads to the so-called Schaefer (1957) harvesting function:

$$H = \alpha L_H S. \tag{4}$$

As long as both goods are produced – which we typically assume to be the case in autarky –, free mobility of labour ensures that wages are identical and that prices are equal to production costs in the two sectors. Therefore,

$$p_H = wa_{LH} = w/(\alpha S); p_M = wa_{LM}. \tag{5}$$

Note that labour costs are the only costs that hunters take into account as the use of the stock S is “free of charge”, given our open-access assumption. As can be seen from equation (5), the price of the harvest good rises, ceteris paribus, with an increase in wages in the economy or with a decrease in the stock of the resource which negatively affects the labour productivity in the harvesting sector.

For a given total resource stock, S, the autarky equilibrium of an economy can be described by the familiar linear Ricardian production possibility frontier (PPF), shown in Figure 1. A country can reach any point on its frontier that is restricted by the maximum producible amount of harvesting ($H = (1/a_{LH})L = \alpha SL$) and manufacturing ($M = (1/a_{LM})L$), respectively. The slope of the frontier (i.e., the relative price of the manufacturing good p_M/p_H) equals $\alpha S a_{LM}$.

Insert Figure 1 approximately here

The exact consumption point on the frontier depends on tastes. Assuming a Cobb-Douglas utility function, a constant share of β and $1 - \beta$ $(0 < \beta < 1)$ of income is spent on H and M, respectively. As the individual species are assumed to be perfect substitutes in consumption, consumers are indifferent from which species' stock z the harvest good comes from. This implies the standard demand functions (denoted with superscripts D):

$$H^D = Lw\beta/p_H; M^D = Lw(1-\beta)/p_M. \quad (6)$$

Substituting prices for production costs from equation (5), yields the output of H and M in the temporary Ricardian autarky equilibrium, shown in Figure 1 by point A on the PPF:

$$H = \alpha\beta LS; M = (1-\beta)(1/a_{LM})L. \quad (7)$$

Note that the larger the preference for the harvest good (i.e., the greater β), the more labour is used in the harvesting sector (which shifts the consumption point along the PPF towards the H-axis). Figure 1 also reveals that with a larger stock S of the resource or a technological improvement in harvesting (rising α), the PPF moves clockwise at $M = (1/a_{LM})L$, raising H.[12]

As laid out in Subsection 3.1, the total stock is an aggregate of the individual species' stocks. Assuming that the Schaefer harvesting function described in equation (4) is valid for all species and that the harvesting technology is identical – which is typically the case in so-called multi-species or bycatch fisheries –, the amount of harvest of a single species $h(z)$ equals

$$h(z) = \alpha\beta Ls(z) = \alpha\beta LS\frac{s(z)}{S}. \quad (8)$$

In combined harvesting, the amount of harvest of a species z thus additionally depends on its relative abundance or, in other words, on the probability of catching an item of species z within the whole stock of resource, $s(z)/S$.

3.3 Steady State in Autarky

The temporary equilibrium becomes a permanent equilibrium if the resource stocks do not change; i.e., $ds(z)/dt = 0$. This holds when the logistic growth function (2) equals harvest (7) for each species z: $r(z)s(z)(1 - s(z)/k) = \alpha\beta Ls(z)$. Solving for $s(z)$ yields the steady state stock $s(z)_A$ in autarky:

$$s(z)_A = k(1 - \alpha\beta L/r(z)). \quad (9)$$

Brander and Taylor (1997a, pp. 536 ff.) show that, for a homogeneous resource, the equilibrium is unique, stable and positive if $r/L > \alpha\beta$. This is also valid for each species z as implied by equation (9). In other words: If $r(z)$ is smaller than or equal to $\alpha\beta L$, the steady state stock will be zero, meaning that the species z will be driven to extinction. As the species differ in their intrinsic growth rate, those with $r(z) < \alpha\beta L$ will not withstand the fishery pressure. This is shown in Figure 2 with r as a function of z and the cut-off-species $\tilde{z}_A$, $r(\tilde{z}_A) = \alpha\beta L$. All the species $z < \tilde{z}_A$ with $r(z) > r(\tilde{z}_A)$ will survive.

Insert Figure 2 approximately here

[12] The amounts of labour used in the two sectors (L_H, L_M) do not change. The same is true for a change in productivity in the manufacturing sector. This is due to the properties of Cobb-Douglas utility and may not hold with a more flexible demand structure.

Using equations (3) and (9), the total stock in the autarky equilibrium then equals

$$S_A = \int_0^{\tilde{z}_A} k(1 - \alpha\beta L/r(z))dz. \tag{10}$$

PROPOSITION 1: An increase in harvesting decreases the stock in two ways: It reduces the number of existing species (extensive margin) and decreases the stock for each of the surviving species (intensive margin).

PROOF: An increase in harvesting is captured by a rise in α, β, or L which reduces the cutoff $\tilde{z}$ as $r(\tilde{z}) = \alpha\beta L$ and $r'(z) < 0$ (see also Figure 2). An increase in α, β, or L decreases the steady state stock of each species remaining in the market. Differentiating equation (9) with respect to β, for example, yields $ds(z)/d\beta = -k\alpha L/r(z) < 0$.

Using (10) in equations (7) and (5), respectively, the steady state quantity and price of the harvesting good follow:

$$H_A = \alpha\beta L \int_0^{\tilde{z}_A} k(1 - \alpha\beta L/r(z))dz; \tag{11}$$

$$p_H^A = w/\alpha S = w/(\alpha \int_0^{\tilde{z}_A} k(1 - \alpha\beta L/r(z))dz). \tag{12}$$

Overall, a country with a relatively strong preference for the resource uses more labour in harvesting and exhibits a smaller index and thus number of species as well as a lower stock of each species. Despite its greater effort in harvesting, the country may well enjoy a lower level of consumption of H (and even of M) and thus a lower standard of living because of the overuse of its open-access resource (the PPF becomes flatter in Figure 1).

3.4 International Trade

Let us now assume two countries – Home and Foreign (*) – in a steady state autarky equilibrium with some positive stocks, where Foreign has a relatively large preference for the resource (i.e., $0 < \beta < \beta^* < 1$). Proposition 1 implies that, ceteris paribus, Foreign has a lower stock of the resource ($S_A^* < S_A$) and a smaller number of species ($\tilde{z}_A^* < \tilde{z}_A$) in autarky (see Figure 2). In addition, Foreign also has a flatter PPF and, therefore, a relatively high price of the harvesting good, $(p_M/p_H) > (p_M/p_H)^*$ (see Figure 1). How do these autarky equilibria differ from the free-trade equilibrium?

Suppose the countries are identical, except for the mentioned taste parameters. Therefore, the demand for the harvest good under the relative free-trade price, $(p_M/p_H)^T$, differs in the two countries:

$$H^D = \frac{w\beta L}{p_H}; H^{D^*} = \frac{w\beta^* L}{p_H}. \tag{13}$$

The world market for the harvest good is assumed to clear (i.e., $H^D + H^{D^*} = H + H^*$). To simplify the analysis, we focus on steady states in which production is diversified in both countries. In this case, total stock sizes in the two countries equalize ($S = S^* = S_T$).[13] Using equation (10) and replacing βL by L_H yields

$$S = S^* = \int_0^{\tilde{z}} k(1 - \alpha L_H / r(z))dz = \int_0^{\tilde{z^*}} k(1 - \alpha L_H^* / r(z^*))dz, \tag{14}$$

where $\tilde{z}$, $\tilde{z}^*$, L_H and L_H^* are endogenously determined. We further know that the intrinsic growth rates at the cutoffs $\tilde{z}$ and $\tilde{z^*}$ equal, respectively,

$$r(\tilde{z}) = \alpha L_H; r(\tilde{z}^*) = \alpha L_H^*. \tag{15}$$

To obtain an explicit solution for the equilibrium values of L_H, L_H^*, $\tilde{z}$, and $\tilde{z^*}$, we assume a simple functional form for $r(z)$, i.e., $r(z) = \bar{r} - z$. $\bar{r}$ denotes the maximum intrinsic growth rate of species $z = 0$. Note that the index z now moves within the interval $[0, \bar{r}]$.[14]

Solving the integrals in equation (14) as well as using (15) and the assumed functional form for $r(z)$, we find the expected result that, in the free-trade equilibrium, the two countries devote the same amount of labour to harvesting (see Appendix, equations (24) to (30)). Thus,

$$L_H = L_H^*. \tag{16}$$

Using equations (13) and (5), we obtain world demand for the harvesting good:

$$H^D + H^{D^*} = \alpha(\beta + \beta^*)LS. \tag{17}$$

This must equal world supply, which denotes

$$H + H^* = \alpha L_H S + \alpha L_H^* S. \tag{18}$$

Equations (16), (17) and (18) imply the amount of labour used in harvesting in the free-trade equlibirium:

$$L_H = L_H^* = \frac{\beta + \beta^*}{2} L. \tag{19}$$

The free-trade cutoff for the surviving species follows, using $\tilde{z} = \bar{r} - \alpha L_H$:

$$\tilde{z_T} = \tilde{z_T^*} = \bar{r} - \alpha \frac{\beta + \beta^*}{2} L. \tag{20}$$

We can now compare the total number of surviving species in autarky and trade. As $\tilde{z} = \bar{r} - r(\tilde{z})$, and $r(\tilde{z}) = \alpha L_H$, we insert the respective $r(\tilde{z})$. For the global index or number of surviving species, the country with the higher number of species in autarky is relevant which is the Home country.

PROPOSITION 2: The number of surviving species is lower in international trade than in autarky.

[13] The reason is that trade in the manufacturing good requires $w = w^*$, which implies that unit costs of the harvested good can only be equal if productivities and, thus, the resource stocks are identical.

[14] This guarantees positive intrinsic growth rates for all potentially surviving species.

PROOF: Home's index of surviving species was $\tilde{z}_A = \bar{r} - \alpha\beta L$ in autarky which is higher than $\tilde{z}_T = \bar{r} - \alpha\frac{\beta+\beta^*}{2}L$; as $\beta^* > \beta$, $\tilde{z}_A > \tilde{z}_T$. This result is also illustrated by Figure 2.

Knowing the species cutoff $\tilde{z}$ and the share of labour in harvesting L_H for Home and Foreign, we can solve for the total resource stocks, the total harvest as well as the price of the resource in the free-trade equilibrium (see Appendix, equations (31) to (33)). They all are equalized by trade as expected.

Note, however, that demand for the resource is larger than supply in the foreign country:

$$H^{D^*} = \alpha\beta^* LS > \alpha\frac{\beta+\beta^*}{2}LS = H_T^*. \tag{21}$$

Thus, Foreign imports the resource good, whereas Home is an exporter of the resource, i.e., an exporter of some of each surviving species.

3.5 Discussion of Resource Extinction

In the homogeneous resource case, an extinction is unlikely. The main force which prevents a homogeneous stock from becoming extinct is the stock externality of harvesting. Unleashed harvesting leads to a reduction in the productivity of the stock ($1/a_{LF} = \alpha S$). If this productivity is low enough, the country will reduce its harvesting as it becomes more profitable to specialize in manufacturing. If Foreign's stock of the resource were depleted below the level reached by Home in an open trade situation, pressure would be taken off the depleted stock in Foreign, since Home benefits from a (temporary) comparative advantage in resource extraction. International trade may, in the homogeneous resource case, work as a counterforce to resource extinction (see Brander and Taylor (1997a,b)).

The vulnerability of the resource, however, increases if we allow for multiple species which are heterogeneous with respect to their intrinsic growth rate, $r(z)$. The reason why extinction (of some species) is more likely in the multiple species framework is due to the fact that the productivity of the resource is less affected by resource decimation. Thus, a country could easily remain specialized in the production of the resource good even if a slow-growing species is driven towards extinction. The existence of faster growing species prevents the *aggregate* productivity (αS) from decreasing sufficiently to make harvesting unprofitable.

The assumption that species are perfect substitutes in consumption is of importance. This implies that there is no (strong) price reaction when a slow growing species is driven to extinction, as the price depends on the stock of the whole resource ($p = w/\alpha S$). Accordingly, the scarcity of an individual species will not lead to price signals that could form the basis for resource management actions as highlighted by Copeland and Taylor (2009). Moreover, international trade always leads to a reduction in the number of species as shown in Proposition 2. The slow-growing species lose the natural protection they enjoyed in autarky in a country with a small demand for the harvesting good.

4 Empirical Analysis

The model predicts that international trade may lead to the fast depletion of a resource that has been thriving in a certain region of the world, if demand for that resource is relatively high in another region. With the resource being composed of heterogeneous species regarding their intrinsic growth rates, international trade tends to endanger particularly the slow-growing species which eventually are driven to extinction. We now want to empirically analyze the assumptions and predictions of the model for the case of sharks.

4.1 International Trade and Open Access

The significance of international trade in global shark production is subject to speculation as official data are lacking. Using, for example, the FAO data reported in Subsection 2.3 on the global production (770,000 tonnes) of Chondrichthyans and the imports of sharks (120,000 tonnes), it is necessary to estimate the share of sharks in the 770'000 tonnes. If we rely on an estimate of 50% by Worm et al. (2013), trade would account for approximately 30% – without taking into account discards, unreported catches and the fact that international trade may consist of a larger share of fins and thus incorporate a higher shark biomass.[15]

We propose a calcuation of the shark biomass associated with international trade in shark fins and compare it with global production of landed sharks, using official FAO data. We thus divide the reported *dried-fin imports* (DFM) by the (wet) shark fin to body-weight ratios (BWR) and the weight ratio of dried to wet fins (WDR). Furthermore, *wet shark fin imports* (WFM) are divided through BWR. Summing the two approximated elements of biomass of dried and wet fins, we get the total shark biomass (BM) embodied in shark fin trade:

$$BM = DFM * \frac{1}{BWR} * \frac{1}{WDR} + WFM * \frac{1}{BWR} \tag{22}$$

The ratios are taken from Biery and Pauly (2012)'s survey who find a mean ratio of 3% for BWR and a mean ratio of 43% for WDR. For the respective weights of dried and wet fins, we rely on the FAO-database (corrected for re-exports to prevent double-counting): 4,989 tonnes for DFM and 8,794 tonnes for WFM. Using equation (22), we obtain a biomass of 680,000 tones of sharks implicitly contained in shark fin trade. Note that this figure is almost as high as global production of Chondrichthyans (770,000 tonnes) reported by the FAO. It thus underscores the major significance of shark fin trade in global shark killing.

We turn to the question of identifying the destination of international trade in sharks. Using UN Comtrade data, Figure 3 reports the import shares of the most important world regions for shark fins (left-hand side) and for shark meat

[15] Along these lines, Clarke et al. (2006) estimate a shark mortality of 1.7 million tonnes of shark biomass per year which is only due to international trade in fins – twice as much as the global production of Chondrichthyans reported by the FAO. Similarly, Worm et al. (2013) estimate a yearly shark mortality of 1,445,000 tonnes, of which finned discards – that are not or only to a small extent captured by FAO statistics – amount to 908,000 tonnes.

including frozen fins (right-hand side) for 2013. The analysis reveals that 95% of internationally traded shark fins are imported by Asian countries.[16] Hong Kong reports the highest dried shark fin imports, accounting for 66% of global imports in 2013. Imports of products other than dried fins are more globally distributed: Brazil, Spain, Italy and Hong Kong are the most significant importers of frozen shark meat (including frozen fins). For all shark products (i.e., all fins as well as frozen, chilled and fresh meat), Asia still accounts for more than half (54%) of the total import value in 2013, followed by Europe with a quarter of all imports (right-hand side). We consider the calculated share of Asia's shark imports as a lower bound estimate.[17]

Insert Figure 3 approximately here

The open-access assumption can be assessed by considering the state of regulations and the changes in the shark stocks. With regard to the former, Campagno et al. (2005, p. 49) recently emphasized that almost all "(...) shark fisheries around the world are virtually unmonitored and completely unmanaged". Similarly, Clarke et al. (2007) state that, despite some recent political actions, shark fishery can still be considered as a mainly unregulated industry. The observed changes in the stocks (see Section 2.4) are in line with this assessment, as most investigated shark populations decreased by more than 50% and thus below s_{MSY}.[18]

4.2 Demand and Supply Characteristics

Given the demand characteristics described in Section 2.2, together with China being a large and fast growing economy, it is not surprising that Chinese shark fin imports dramatically increased, particularly in the 1990s. The wide range of shark species caught for shark fin soup (see Vannuccini (1999)) supports the model's assumption that shark species are highly substitutable in consumption. According to Kreuzer and Ahmed (1978), fins from all sharks which are larger than approximately 1.5 meters long can be used for shark fin soup. Consumers of shark fin soup are largely indifferent as to which shark species ends up in their soup. Eriksson and Clarke (2015, p. 168) report that a "substitution between species can be easily accomplished at the retail level since there is often no species information provided at the point of sale". Campagno et al. (2005) note that even if consumers wanted to know, it would be difficult for them to find out which shark species they were eating.

[16] Similar values result if we calculate the share of shark fin imports based on weight rather than value using UN Comtrade- or FAO-data. Asia has stable fin import shares of above 90% over time. While UN Comtrade figures do not separately report imports of frozen fins, tje FAO data confirm that the Asian import shares of frozen fins were comparably high in 2011 (92% of global import value).

[17] In 2013, Mainland China valued imports of shark fins at 339,000 US$, while other countries valued exports to Mainland China at more than 9,153,000 US$ in the official UN Comtrade data.

[18] See also Baum et al. (2003) who report that the abundance of all species (except one) of sharks caught by the North Atlantic longline fleet declined by more than 50% over the investigated (and relatively short) time periods (1986 to 2000 and 1992 to 2000). WildAid (2014, p. 8) reports recent reductions ranging from between 40% and 99.99% of the stock for 11 species.

Campagno et al. (2005, p. 45) also support the model's prediction regarding combined harvesting: "Sharks are probably taken in largest quantities worldwide in coastal multi-species or 'catch all' fisheries". According to their analysis, fisheries which target specific shark species are rather exceptional. Beerkircher et al. (2008) emphasize the high shark mortality owing to the bycatch of pelagic longline fisheries which target tuna and swordfish.

4.3 Risk of Extinction

Given the large heterogeneity among shark species described in Subsection 2.1, we suspect a high level of diversity in the intrinsic growth rates. We proxy the intrinsic growth rate with the "rebound potential" defined as the "population's ability to rebound when fishing mortality is removed" (Klimley (2013, p. 455)). In terms of the Gordon-Schaefer model, this measure equals the resource growth ($\frac{g(s)}{s(z)}$) at the maximum sustainable yield stock, s_{MSY} (see Smith et al. (1998, p. 664)). Species with a higher intrinsic growth rate, r, also have a higher rebound potential.[19]

Worm et al. (2013) estimate the rebound potential for 62 shark species, based on the methodology of Smith et al. (1998). The results are presented in Figure 4: There is a wide range of rebound potentials among the assessed shark species. Mustelus californicus (Grey smooth-hound) is reported to have the highest (0.121), Centrophorus squamosus (Leafscale gulper shark) to have the lowest rebound potential (0.0095). The Rhincodon typus (whale shark) has a rebound potential of 0.01, the Carcharadon carcharias (great white shark) one of 0.04.

Insert Figure 4 approximately here

The rebound potential of sharks is, on average, relatively low. From the perspective of our model, a comparison with tunas or swordfish is interesting. Klimley (2013) lists the southern bluefin tuna (Thunnus maccoyii) with a rebound potential of 0.06-0.09 and the swordfish (Xiphias gladius) with one of 0.07-0.096. Tropical tunas have even faster reproduction rates: The skipjack tuna (Katsuwonus pelamis) has a rebound potential of 0.16-0.34, and the yellowfin tuna (Thunnus albacares) of 0.10-0.18. These rebound potentials are higher than those of most shark species plotted in Figure 4. This highlights the danger of fisheries targeting tuna or swordfish, while keeping slow growing sharks as bycatch.

To analyze the theoretically implied relationship between (i) the risk of extinction of individual shark species, (ii) their intrinsic growth rate, and (iii) their existence in international trade, we use the species ranking for sharks provided in the IUCN Red List introduced in Subsection 2.4 as a proxy for the extinction risk.[20] IUCN categorizes shark species according to labels indicating their vulnerability: "least concern" (coded 0), "near threatened" (coded 1),

[19] If the assumption of the logistic growth function is met, the value of the rebound potential is half of the intrinsic growth rate, r, used in the theoretical part.

[20] This ranking is also used by other researchers (e.g. Field et al. (2009), Dulvy et al. (2014)).

"vulnerable", "endangered", "critically endangered" (all coded 2). The largest sample consists of 262 shark species.[21]

The explanatory variables that are used to explain the position of shark species in the IUCN Red List include, first, a dummy variable denoting whether a species is part of shark fin trade or not ($intrade_i$); as mentioned above, species that do not exceed a length of 1.5 meters are not interesting for the shark fin trade. We employ a conservative and a less conservative list of species. The conservative list includes 14 species which, according to SharkSavers (a program of WildAid), are "prevalent" in the shark fin trade.[22] A longer list (intrade_long) additionally includes species mentioned in Vannuccini (1999) as well as species which were confiscated on board of (Indonesian) IUU vessels in Australian waters and later identified by DNA analyses in Marshall (2011) and Holmes et al. (2009).

The second explanatory variable is the rebound potential ($rebound_i$), as used in Figure 4. As these rebound potentials are only available for a small group of sharks, we start the analysis by using an ordinal indicator on the "resilience" of species. This indicator reflects the biological resilience of a species, which is ranked according to four categories: very low (coded 0), low (coded 1), medium (coded 2), and high (coded 3).[23] Shark species mostly fall in the categories 0 to 1, no species falls into category 3. We use this indicator for the larger sample estimation, before looking at the rebound potentials mentioned above in a smaller sample.

The three control variables describe biological or spatial aspects of shark species behavior: The (1) minimum and (2) maximum ocean depths which each species inhabits and (3) a dummy variable whether a species is pelagic or not. These three variables should control for the catchability of a species: Pelagic species are able to move across oceans, they are thus more widely distributed across the globe and should therefore be less prone to extinction than species concentrated on a specific coast. The depth parameters control for variation in catchability among species. Species which dive down to lower depths may be less vulnerable to overfishing, as they have a habitat outside the range of most fishing gear.

We test the following hypotheses: The species which are caught for the shark fin trade are more likely to belong to a class that is closer to extinction. Moreover, species which have a fast intrinsic growth rate are, ceteris paribus, likely to be part of a less endangered class (and thus of a lower IUCN-category). Our estimating equation is therefore formulated as follows:

$$IUCN_i = \alpha + \beta_1 intrade_i + \beta_2 rebound_i + \gamma X_i + \epsilon_i. \qquad (23)$$

As the dependent variable is an ordinal indicator, we use an ordered logit model which estimates the probability of a species being in one of the three

[21] All variables except the "Intrade"-measures and the rebound potential (sources mentioned below) were accessed through the Fishbase database, accessible under www.fishbase.org (downloaded 5.5.2014).

[22] http://www.sharksavers.org/en/education/sharks-are-in-trouble/the-impact-of-the-shark fin-trade (accessed 05.01.2015).

[23] Very low=minimum population doubling time more than 14 years; low=minimum population doubling time 4.5-14 years; medium=minimum population doubling time 1.4-4.4 years; high=minimum population doubling time less than 15 months.

categories, given their characteristics.[24] We report odds ratios in all tables.

Insert Table 1 approximately here

Table 1 starts with the longer list of internationally traded species used in the regressions. We see that a shark species' probability of being close to extinction increases if it is part of shark fin trade (intrade_long). The odds ratios suggest that the odds of being in a higher extinction risk category increases by a factor between 1.37 and 1.74. The control dummy for pelagic species is insignificant in all specifications, whereas the minimal depth reached by a species is significant at the ten-percent level and negative in all specifications in which it appears (3-5). These results indicate that the deeper the minimal depth (and thus the lower the catchability) of a species, the smaller the extinction risk. The maximal depth and the resilience of species do not significantly affect the risk of extinction.[25] Note that the estimation in column (3) of Table 1 is the one preferred according to the Akaike information criterion (AIC).

As the ordinal resilience indicator blurs the differences between the species' rebound potentials, we now use the rebound potentials available for a subset of species in the regressions. Unfortunately, the sample then shrinks to only 53 observations – or even less in some specifications. In the basic specifications, we have 17 observations in IUCN-category 0, 15 observations in IUCN-category 1, and 21 observations in IUCN-category 2.

Insert Table 2 approximately here

The results in Table 2 imply that the coefficients of interest have the expected sign and are significant: A higher rebound potential (rebound) reduces the probability of being close to extinction. The result is visualized in Figure 5 which plots the species' predicted probabilities of being in a specific IUCN-category, conditional on their rebound potential.[26] The probability of being endangered is above 0.5 for species with rebound potentials of less than 0.02, while it is less than 0.2 for species with a rebound potential of more than 0.1. Though the trade variable (intrade_long) is significant in specifications (2) and (3), it becomes insignificant in specifications (4) and (5); we suspect the smaller sample size in these specifications to cause this result.

Insert Figure 5 approximately here

[24]The main results are robust to probit estimation. We also perform Brant and likelihood-ratio tests to check if the parallel-line assumption holds. As some tests reject the assumption (Brant and LR tests quite often disagree on the same specification), we re-estimate all specifications using the generalized ordered probit model which does not rely on the proportional odds assumption (using Williams (2006)'s Stata package gologit2). The results remain qualitatively unchanged and are available from the authors upon request.

[25]We repeat the same estimations replacing the long list of "intrade species" by the shorter list, and receive almost identical results.

[26]Predicted probabilities are based on specification (5) in Table 2. The other controls were evaluated at their means.

4.4 Future

Whether the pressure on sharks, particularly on slow-growing species, will continue in future not only depends on possible effects of recent regulations, but also on the information consumers of shark fins have and how they react to it. In this regard, WildAid (2014) reports that its awareness campaigns – showing the detrimental effects of shark fin soup consumption on the shark population, the low nutritional value, the high mercury content and the existence of fake shark fins – have affected consumer behavior. It is argued that sales declined by 80% from 2012 to 2013 in Guangzhou (which the organization believes to be the new center of the shark fin trade) and 85% of the consumers "said they gave up shark fin soup within the past three years" (WildAid (2014, p. 2)). In addition, the Chinese government prohibited shark fins from being served at official events in 2012.

The most recent UN Comtrade data only partly confirm this interpretation. Hong Kong reported 3,319 tonnes of dried fin imports in 2012; this was followed by a considerable decrease of 20% in 2013 (2,659 tonnes). However, fin imports stabilized and equaled 2,693 tonnes in 2014. Eriksson and Clarke (2015) offer three explanations for the apparent decrease in traded shark fins: regulations against finning and the fin trade, a decrease in the stock of sharks and a decrease in demand owing to campaigns discouraging consumption in China.

An inspection of the change in the unit values may help to discriminate between these explanations: whereas the first two explanations tend to increase the market price of shark fins, the third one would reduce it. Assuming that the quality and the mix of Hong Kong imports remains comparable between 2012 and 2014, unit prices provide us with an indication of shark fin prices. We find that prices fell from 46.7 US$ per kg in 2012 to 35.9 US$ in 2013, and then to 33.3 US$ in 2014.[27] If this reflects a fundamental change in preferences, it may be an encouraging sign for the sharks' future.

5 Conclusion

This paper has been motivated by the disconcerting depletion of sharks on our planet. We were surprised by the extent of their decimation and affected by the cruelty involved in the killing of these, as we found out, principally shy and peaceful animals – at least towards human beings – with all their special capabilities, increasingly pointed out by marine biologists. We were worried about their fate and concerned about the potential effects that the ongoing depletion and possible extinction of this apex predator would have on the oceanic ecosystems. We therefore wanted to understand the mechanisms that have led to this situation and evaluate the fate of sharks.

An analogy arose in our mind to the analysis of the virtual extinction of the American Bison in the 1870s by Scott Taylor (2011). In his research, international trade is identified as an important causal factor together with the exploding demand in Europe for Buffalo hides which was precipitated by

[27] For comparison, we calculated the unit values of fin imports to Hong Kong reported by FAO in the category "Shark fins, dried, salted, etc.". The average import unit value of shark fins between 1990 and 2011 was also at a higher 39 US$.

a tanning innovation which allowed the hides to be used in various industrial applications: "(...) once the tanning of buffalo hides was possible, the value of a kill was soon dominated by the value of a hide. Historic accounts are clear that the introduction of the hide market vastly increased the return to buffalo hunting so that most meat was left to rot on the plains (...)" (Taylor (2011, p. 3175)). Our investigation of the shark case implies the following similarities and differences to the "Slaughter on the Plains" (Taylor (2011, p. 3162)).

First, as in the Buffalo case, sharks can be considered an open-access resource. Secondly, international trade is also an important element in the case of shark depletion. Without trade, sharks would be under much less pressure in most of the oceanic regions. Thirdly, sharks have been decimated particularly because of their fins. The intensity and manner of shark killing for this purpose is closely associated with the much higher price of fins compared to that of shark meat. Again, this is similar to the case of the American Bison which was hunted solely for the value of its hide at the time. Fourth, both studies identify the detrimental effects of a rise of demand for the species in another region of the world: in the case of the buffalo this was Europe, and in the case of the shark today, this is mainly Asia.

There are, however, differences. First, relative prices of individual shark species may remain unchanged and thus not reflect their relative scarcity because of perfect substitutability of shark fins in consumption and combined harvesting. This is different to the case of the American Bison which was not composed of heterogeneous species. Note that it could, however, be argued that the observed absence of a price increase of buffalo hides contains a similarity to our case as the relatively abundant cattle hides were substitutes to the buffalo hides. Secondly, the heterogeneity of shark species regarding their intrinsic growth drastically increases the risk of extinction for the slow-growing shark species as shown in our paper. Thirdly, on the positive side, sharks may benefit from the fact that information spreads more quickly today than in the 1870s. While Europeans hardly received timely information on the effects that their run on hides was having on the American Buffalo, consumers of shark fins in today's global economy are confronted with information that may affect their behavior and improve the sharks' destiny.

In future, tight restrictions on the sale or export of shark products, slowly being put in place by some countries for certain particularly endangered species, may have some effect on shark hunting, in spite of smuggling and corruption. Raising the awareness of consumers, particularly in Asian countries, appears to be a potentially promising complementary strategy. However, it remains to be seen whether the forces responsible for this apparent reduction in demand are sufficiently far-reaching, persistent and timely enough. Further immediate action is required to give *all* shark species a chance of survival.

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Figure 1: Production Possibility Frontier

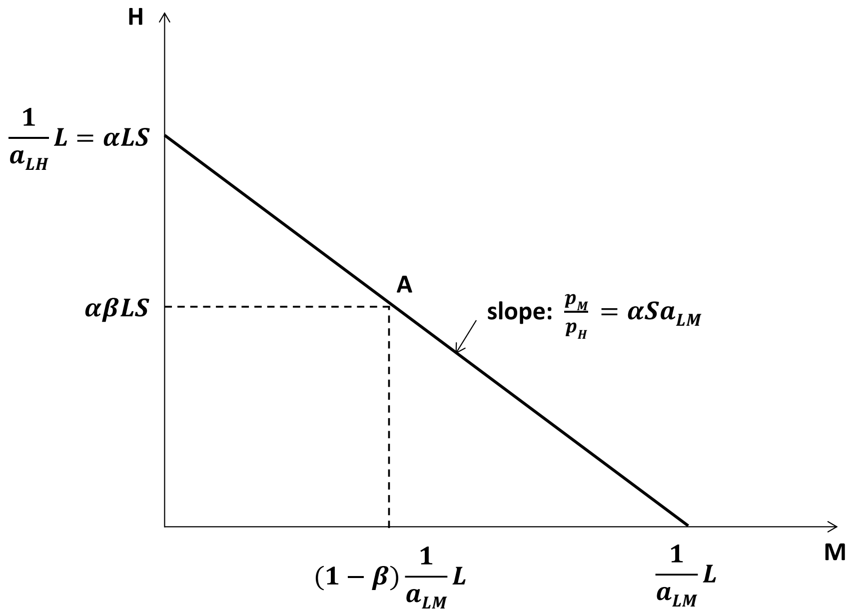


Figure 2: Species in Autarky and Trade

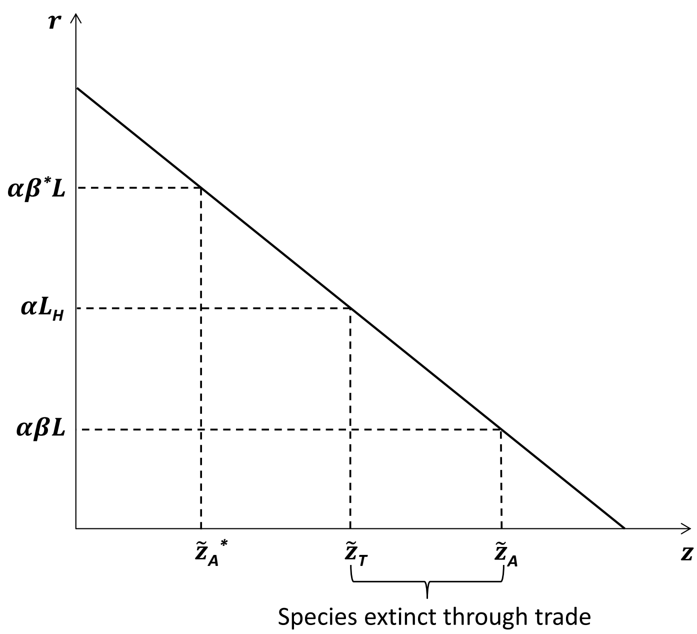
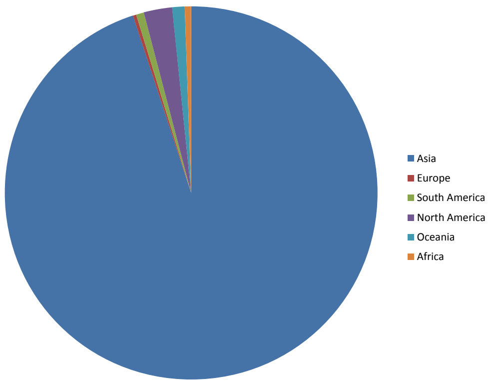
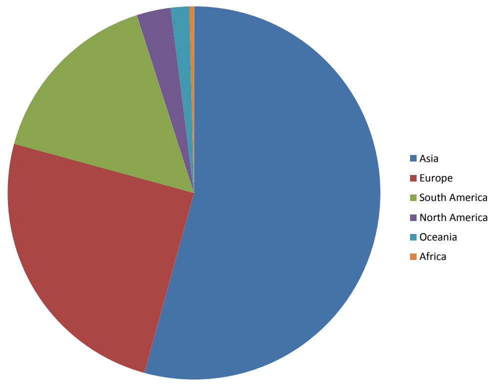


Figure 3: Shark Import Shares 2013 (Source: UN Comtrade Database)



(a) Shares of (Non-Frozen) Shark Fin Imports (HS 030571)



(b) Shares of Total Shark Product Imports (HS 30281, 30265, 30375, 30381, 030571)

Figure 4: Histogram of Rebound Rates of 60 Shark Species (Source: Worm et al. (2013))

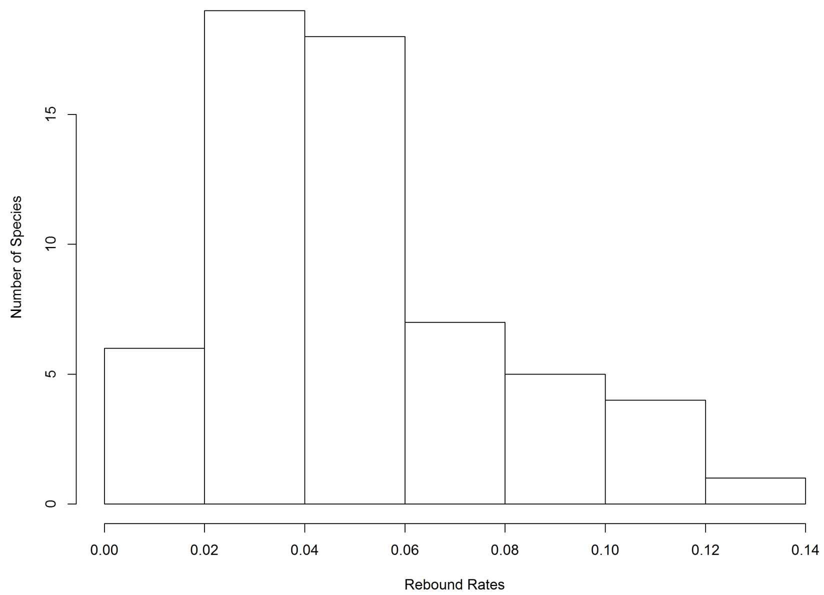


Table 1: Ordered Logit Estimation, Long Intrade List

	(1)	(2)	(3)	(4)	(5)
	iucn2	iucn2	iucn2	iucn2	iucn2
intrade_long	1.372***	1.740***	1.629***	1.626***	1.546***
	(5.22)	(5.96)	(4.46)	(4.47)	(4.15)
pelagic		-0.165	0.180	0.185	0.211
		(-0.51)	(0.45)	(0.47)	(0.54)
mindepth			-0.00314*	-0.00311*	-0.00304*
			(-1.83)	(-1.79)	(-1.78)
maxdepth				-0.0000287	-0.0000442
				(-0.16)	(-0.23)
resilience					-0.212
					(-0.62)
N	262	233	168	168	168
pseudo R^2	0.039	0.063	0.111	0.111	0.112
chi2	27.22	35.67	36.30	36.40	37.31
AIC	541.0	464.9	330.9	332.9	334.4

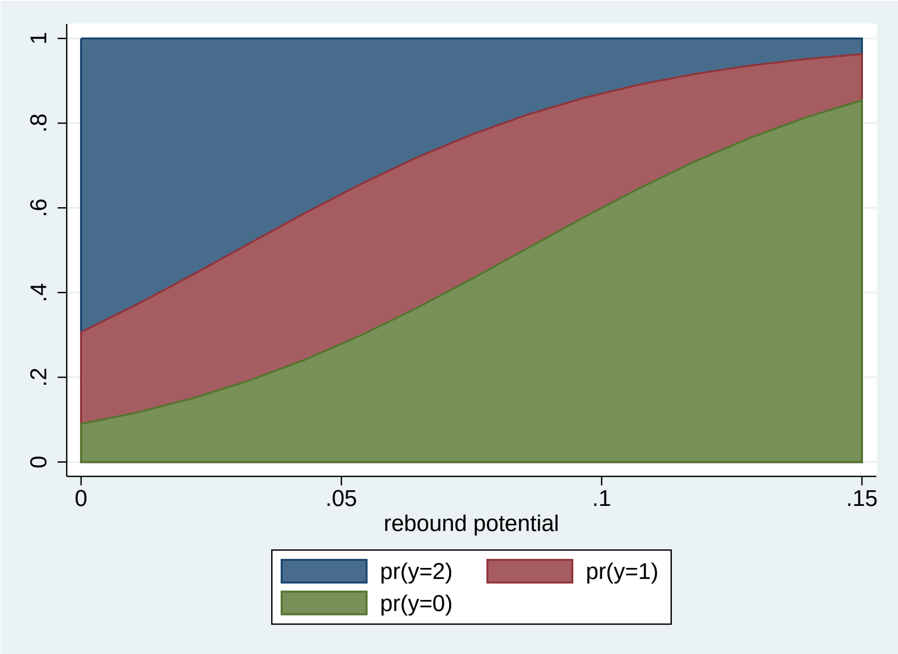
t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2: Ordered Logit Estimation, Rebound Potentials

	(1)	(2)	(3)	(4)	(5)
	iucn2	iucn2	iucn2	iucn2	iucn2
rebound	-29.79***	-27.03***	-27.21**	-31.79***	-31.97***
	(-2.63)	(-2.67)	(-2.44)	(-2.63)	(-2.65)
intrade_long		1.662***	1.294**	1.154	1.164
		(2.81)	(2.17)	(1.55)	(1.49)
pelagic			1.028	1.553*	1.550
			(1.32)	(1.65)	(1.64)
mindepth				-0.00757	-0.00736
				(-0.79)	(-0.78)
maxdepth					-0.0000327
					(-0.11)
N	53	53	52	42	42
pseudo R^2	0.076	0.153	0.169	0.210	0.210
chi2	6.936	17.56	17.75	18.34	18.71
AIC	112.7	105.7	103.8	82.56	84.55

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 5: Stacked IUCN-Category Probabilites of Shark Species Conditional on Rebound Potential



6 Appendix

Equation (16) can be derived by solving the integrals of equation (14) for L_H and L_H^*:

$$\int_0^{\tilde{z}} k(1-\alpha L_H/r(z))dz = \int_0^{\tilde{z^*}} k(1-\alpha L_H^*/r(z^*))dz. \quad (24)$$

We factor out k to receive

$$k\int_0^{\tilde{z}} (1-\alpha L_H/r(z))dz = k\int_0^{\tilde{z}} (1-\alpha L_H^*/r(z^*))dz. \quad (25)$$

Further, we split the subtractions in two functions with integrals:

$$k[\int_0^{\tilde{z}} 1dz - \alpha L_H \int_0^{\tilde{z}} 1/r(z)dz] = k[\int_0^{\tilde{z}} 1dz - \alpha L_H^* \int_0^{\tilde{z}} 1/r(z^*))dz]. \quad (26)$$

We solve $\int_0^{\tilde{z}} 1dz = \tilde{z}$. To solve the integral $\int_0^{\tilde{z}} 1/r(z))dz$, we assume that $r(z) = \bar{r} - z$. This integral then solves to $ln(\bar{r}) - ln(\bar{r} - \tilde{z})$. We get:

$$k[\tilde{z} - \alpha L_H(ln(\bar{r}) - ln(\bar{r} - \tilde{z}))] = k[\tilde{z^*} - \alpha L_H^*(ln(\bar{r}) - ln(\bar{r} - \tilde{z^*}))]. \quad (27)$$

To solve for L_H and L_H^*, we use $\tilde{z} = \bar{r} - \alpha L_H$ and $\tilde{z^*} = \bar{r} - \alpha L_H^*$ to receive

$$k[\bar{r} - \alpha L_H - \alpha L_H ln(\bar{r}) + \alpha L_H ln(\alpha L_H)] = k[\bar{r} - \alpha L_H^* - \alpha L_H^* ln(\bar{r}) + \alpha L_H^* ln(\alpha L_H^*)]. \quad (28)$$

We divide by k, subtract $\bar{r}$, divide by α and then use e to get:

$$\frac{\alpha L_H e^{L_H}}{re^{2L_H}} = \frac{\alpha L_H^* e^{L_H^*}}{re^{2L_H^*}}. \quad (29)$$

We can now solve for the ratio of L_H to L_H^* to find that

$$\frac{L_H}{L_H^*} = e^{L_H - L_H^*}, \quad (30)$$

which solves for $L_H = L_H^*$.

The total resource stocks in free trade follow from equation (28) and (20):

$$S_T = S_T^* = k(\bar{r} - \alpha\frac{\beta+\beta^*}{2}L(1 + ln(\bar{r}) - ln(\alpha\frac{\beta+\beta^*}{2}L))). \quad (31)$$

Furthermore, equilibrium harvest in Home and Foreign follows by imputing these stocks and the share of labour derived in (19) in the harvesting equation (4).

$$H_T = H_T^* = \alpha\frac{\beta+\beta^*}{2}Lk(\bar{r} - \alpha\frac{\beta+\beta^*}{2}L(1 + ln(\bar{r}) - ln(\alpha\frac{\beta+\beta^*}{2}L))), \quad (32)$$

Finally, the resource price under free trade p_H^T can be derived by using equations (12) and (31):

$$p_H^T = w/(\alpha k(\bar{r} - \alpha\frac{\beta+\beta^*}{2}L(1 + ln(\bar{r}) - ln(\alpha\frac{\beta+\beta^*}{2}L)))). \quad (33)$$