Do exports of renewable resources lead to resource depletion? Evidence from fisheries*

Sabrina Eisenbarth†

In the case of fisheries, exports are an important cause of resource depletion. This paper uses novel and detailed country-species-level fisheries data to estimate the causal effect of a fishery's exports on the collapse of the fishery. Identification is based on an export demand shock originating from Japan. The results reveal that an increase in logged exports by one standard deviation raises the probability of a fishery's collapse in the following period by 29 percentage points. Only fisheries without catch share programs collapse when exports surge.

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†University of Exeter Business School and Land, Environment, Economics and Policy Institute (LEEP), Xfi Building, Rennes Drive, Exeter, EX4 4PU, UK, s.eisenbarth@exeter.ac.uk, phone: +447522183794

1 Introduction

The depletion of renewable resources is becoming ever more prevalent. Forest cover loss, fisheries collapse and the endangered status of countless animal and plant species are prominent examples (FAO, 2016*a*; Pinsky et al., 2011; Costello et al., 2012; IUCN, 2018). Renewable resources are important export products, particularly in the developing world, yet we still have a poor understanding of the extent to which trade contributes to resource depletion and collapse. Empirical studies on trade in renewable resources are limited by at least one of the following: a lack of causal inference, a lack of species level information on trade flows and resource stocks, and a lack of external validity due to a focus on selected species. Existing research focuses on the effect of trade in forest products (Abman and Lundberg, 2020; Faria and Almeida, 2016; Ferreira, 2004; Tsurumi and Managi, 2014), ivory (Barbier et al., 1990) and buffalos hides (Taylor, 2011). Causal insights on the effect of fisheries exports on fish stocks are missing.

This paper uses detailed fisheries data to estimate the causal effect of fisheries exports on the collapse of fisheries. The paper employs a novel identification strategy, using an export demand shock originating from Japan as an instrument for exports in the rest of the world. The use of country-species-year level data on trade in fishery products yields detailed insights about the way exports affect the collapse of numerous different fish species. The results suggest that an increase in exports leads to a large increase in the probability of a collapse, predicting roughly two thirds of the observed increase in the percentage of collapsed fisheries. This paper also highlights the importance of institutions, since exports only seem to deplete fisheries that are not regulated via catch share programs such as individual transferable quotas (ITQs).

Fisheries are a particularly interesting resource to study since they are both highly traded and threatened by resource collapse. Indeed, fishery products have become one of the most highly traded food commodities and more than one third of global fish production is exported (FAO, 2016*b*). At the same time, the world's fisheries are overfished and between 17% and 25% of the world's fisheries have collapsed (Pinsky et al., 2011; Costello et al., 2012). This begs the question whether exports cause the collapse of fisheries.

Insights on the effect of fisheries exports on fisheries collapse are especially important for developing countries, which produce more than half of global fisheries exports (FAO, 2016*b*). In the developing world, fisheries generate up to 50% of export revenue (Bellmann, Tipping and Sumaila, 2016) as well as employment for more than 37 million people (FAO, 2016*b*). Moreover, fish is an important source of animal protein for consumers around the world. Yet, all of these benefits are short-lived if fisheries collapse as a result of exports.

From a theoretical point of view, open access renewable resources do not necessarily collapse in exporting countries. Brander and Taylor (1997*a*,*b*, 1998); Chichilnisky (1994) and Hannesson (2000) show that the resource stock declines when a country exports an open access renewable resource. However, only Copeland and Taylor (2006) and Gars and Spiro (2018) discuss the possibility of a resource collapse.

To guide the empirical estimation, this paper illustrates that exports can cause the collapse of an open access renewable resource that is viable in autarky. The illustration is based on a Ricardian model similar to Brander and Taylor (1997*a*) and Copeland and Taylor (2006) and the paper focuses on a situation in which a trade liberalization is associated with an exogenous increase in the resource price. This increase in the price makes harvesting more lucrative and, as a result, the country harvests more and exports the renewable resource. Since harvest exceeds resource growth, the resource stock shrinks over time. At high world market prices, exporting can lead to the collapse of an open access renewable resource if harvesting capacity is high relative to the resource growth rate.

The empirical analysis provides the first estimate of the causal effect of fisheries exports on the collapse of fisheries. This paper uses a standard definition of fisheries collapse (see e.g. Worm et al., 2006; Costello, Gaines and Lynham, 2008) and defines a species in a particular country as collapsed if catch is below 10 percent of the maximum catch recorded since 1950. This approach is necessary since scientific stock assessments are sparse and they mostly focus on high value and often well-managed stocks in the US, Canada, Australia and New Zealand. Hence, assessed fisheries do not represent a random sample and an analysis based on assessed stocks cannot shed light on dynamics in major exporting fisheries in the developing world. That said, a robustness test using data from stock assessments substantiates this paper's findings.

The collapse of Japanese fisheries is used as an instrument for exports of fishery products in order to make causal inference. The analysis exploits substantial variation in the collapse of Japanese fisheries at the species-year level. Since Japan is one of the largest markets for seafood products, the collapse of a fish species in Japan raises the world market price and spurs exports of the affected species from other countries. The instrumental variable estimation is necessary since both exports and the probability of a collapse in the following year depend on the size of the fish stock, which is unobserved. Therefore, the results from a simple OLS regression would be biased downwards.

The empirical strategy takes two steps to ensure that trade is the only channel through which a collapse in Japan can affect a collapse in the exporting country. First, the sample does not include fisheries that are shared between Japan and the exporter. When stocks are shared, a collapse of a species in Japan could directly affect the collapse in the exporting country. Second, the empirical model controls for other economic, biological and climatic factors that could lead to the collapse of fisheries in both countries.

The analysis is based on a newly-constructed, comprehensive country-species level panel dataset which allows for both detailed and broadly applicable insights on the effect of exports on resource depletion. Insights are detailed since the analysis links trade flows to data on fisheries collapse for every species in every country in the dataset. Every country-species combination represents one fishery in the context of this paper. The panel dataset covers around 100 countries and more than 100 fish species from 1976 to 2006. Due to the large number of species in the dataset, the results provide more external validity than most other studies in the literature on trade in renewable resources.

The paper shows that exports significantly contribute to the collapse of fisheries. The results suggest that an increase in exports by one percent raises the probability of a fishery's collapse in the following year by around 0.1 percentage points. This is a large effect, particularly considering the surge in exports of fishery products in the last few decades. Exports in the median fishery grew by 53 percent between 1991 and 2006. According to the estimates, this export boom raised the probability of a collapse by 6 percentage points. This predicted increase in fisheries collapse is equivalent to roughly two thirds of the observed increase in the proportion of collapsed fisheries during that time period.

The results suggest that exports only lead to a collapse of fisheries that are not regulated through individual transferable quotas (ITQs) or other catch share programs.[1] Therefore, the result of this paper suggest that trade openness should

[1]This is in line with the literature's finding that trade openness leads to the overharvesting of

be accompanied by sustainable fisheries or resource management. Developing countries which rely heavily on income and export revenue from fisheries would likely benefit most from the adoption of sustainable regulations to guarantee long-term gains from fisheries exports.

This paper contributes to the existing empirical literature on trade in renewable resources in three main ways. First, it estimates the causal effect of exports on the depletion of a renewable resource using a novel instrumental variable.

Second, this paper provides better estimates of the effect of resource exports on resource depletion since it uses relevant information on resource trade flows at a very disaggregated level. To be precise, the analysis is based on species level fisheries exports, whereas existing papers use country level exports plus imports relative to GDP (see e.g Ferreira, 2004; Faria and Almeida, 2016; Erhardt, 2018) or the implementation of regional trade agreements (Abman and Lundberg, 2020) as measures for trade openness. The use of species-level data is an improvement over existing country-level analyses. A country can export some fish species and import other fish species. Trade openness would protect the stocks of imported species (Brander and Taylor, 1997*a*,*b*) and deplete stocks of exported species. This important distinction is lost in aggregate datasets. The use of species-level resource trade flows allows for a crucial distinction between effects of resource exports and imports.[2]

Finally, this paper analyses the effect of fisheries exports on the depletion of broad set of fisheries, whereas most of the existing literature focuses on other resources. To date, Erhardt and Weder (2015) and Erhardt (2018) provide the only empirical analyses of the relationship between trade openness and overfishing. However, neither of those papers can quantify the effect of fisheries exports on the depletion of fisheries due to a lack of fisheries trade data.[3] Based on both detailed

renewable resources, particularly if they are unregulated (see e.g. Barbier et al., 1990; Ferreira, 2004; Taylor, 2011). Taylor (2011), e.g, argues that exports of bison hides contributed to the near extinction of the North American bison under open access conditions. Bulte and Barbier (2005), Fischer (2010) and Copeland (2011) provide more comprehensive reviews of the relevant literature on trade in renewable resources.

[2]This paper's empirical strategy cannot be used to analyse the effect of fisheries imports on a stock's potential recovery. Imports seem to be very price-inelastic and the collapse of fisheries in Japan is not associated with a significant reduction in imports in the rest of the world. Hence, the collapse of Japanese fisheries is only a weak instrument for imports in other countries. Therefore, this paper does not analyse importing fisheries and it does not assess the overall effect of trade on fish stocks globally.

[3]Erhardt (2018) investigates the effect of trade openness on the proportion of collapsed species at the country level. The paper uses country-level exports plus imports relative to GDP and

and comprehensive fisheries trade data and a novel instrumental variable, this paper can, for the first time, estimate the causal effect of exports from a particular fishery on the collapse of that fishery.

This paper is structured as follows. Section 2 illustrates the theoretical background for the analysis. The empirical strategy is presented in Section 3, which discusses the potential bias in the OLS regression and explains the choice of the instrument as well as the estimating equation. Section 4 explains the construction of the novel dataset and describes relevant patterns in the data. The results from a benchmark OLS regression and an instrumental variable regression are presented in Section 5. Dynamics are discussed in Section 6. This is followed by a sensitivity analysis in Section 7. Section 8 concludes.

2 Theoretical illustration: Exporting can lead to the collapse of fisheries

This section uses a simple Ricardian trade model like Brander and Taylor (1997*a*) and Copeland and Taylor (2006) to derive the hypotheses for the empirical analysis. Moreover, it illustrates under which circumstances exporting leads to the collapse of a fishery that is viable in autarky. The discussion focuses on a situation in which opening up to trade is associated with an exogenous increase in the price of fish. As a result of this increase in the price, fishing becomes more lucrative and the country instantly produces and exports more fish. Due to this additional fishing pressure, the catch of fish exceeds resource growth and the stock declines over time. At high world market prices, a fishery can collapse if fishing capacity is high relative to the resource growth rate.

This section provides an intuitive explanation of the way trade affects the fishery. Technical details are deferred to Section 9 in the Appendix.

a country-level index for globalization as proxies for trade in fishery products. Erhardt and Weder (2015) find a positive correlation between a shark species' IUCN red list status and a dummy variable, which indicates whether a shark species is traded internationally, but do not provide causal insights.

2.1 Model setup

The economy consists of two industries: Fishing and manufacturing. The total labour supply is L_T. L_H workers are employed in the fishing industry,[4] and the manufacturing industry employs L_M workers.

Manufacturing production technology is given by $M = L_M$. The price of the manufacturing product is normalized to 1. Therefore, the wage rate in manufacturing equals $w = 1$. Labour is assumed to be mobile across industries and hence the wage rate in fishing must also equal 1 in a diversified economy.

Prior to a description of the fishing industry, this section explains the resource stock dynamics. In every period, the fish stock is given by $S(t)$. Changes in the fish stock dS/dt are a function of natural resource growth $G(S(t))$ and resource harvesting (i.e. fishing) $H(t)$, such that

$$dS/dt = G(S(t)) - H(t). \tag{1}$$

Natural resource growth is characterized by a commonly used logistic function with an intrinsic resource growth rate r and a carrying capacity K. Following Copeland and Taylor (2006), the resource growth function used in Brander and Taylor (1997*a*) is extended by a minimum viable stock size $\underline{S}$ to obtain

$$G(S(t)) = r\left(S(t) - \underline{S}\right)\left(1 - \frac{S(t)}{K}\right). \tag{2}$$

This resource growth function is depicted by the blue dashed line in Figure 1. The graph shows that resource growth is only positive if the stock exceeds the minimum viable stock size $\underline{S}$. If $S < \underline{S}$, the stock is depleted and does not replenish naturally.

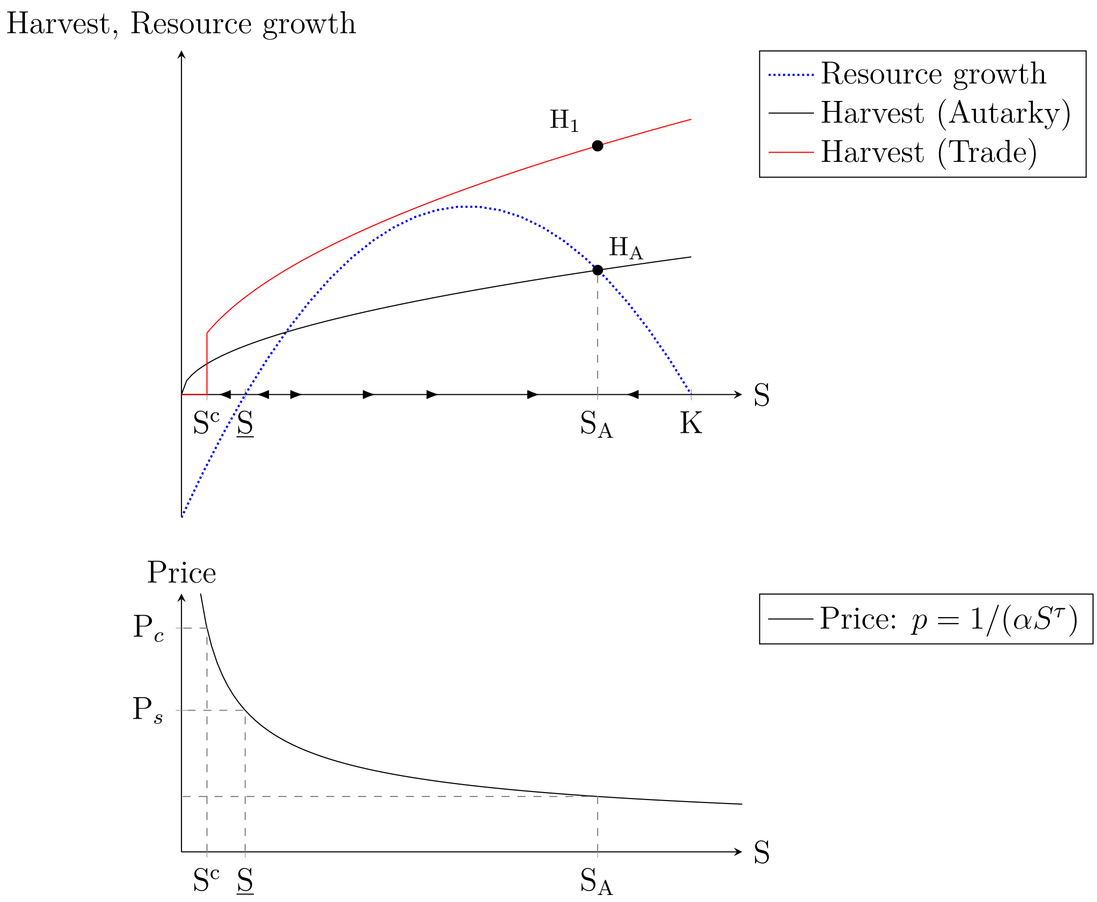
Fishing is characterized by the following function in which α describes the fishing technology and $\tau \geq 1$ is a schooling parameter.

$$H = \alpha S^{\tau} L_H \tag{3}$$

The term αS^{τ} in this equation captures fishing productivity. Each worker in the fishing industry catches more if technology α is more advanced or if the stock is larger. The extent to which the catch depends on the stock size is measured by τ.

[4] The notation follows Brander and Taylor (1997*a*), where H represents harvesting of renewable resources.

Figure 1: Resource dynamics and catch function



The bottom panel of Figure 1 shows all price-resource stock combinations that yield a diversified pattern of production. See Section 9.2 in the Appendix for details.

Schooling fish species are relatively easy to catch when the stock is small. When a species forms schools, τ is low and fishing productivity is not very responsive to the stock size.

The fishery is assumed to be unregulated. Open access to the fishery results in zero profits such that the revenue from fishing equals the fishing cost. With the catch function described by Equation 3, open access to the fishery and Cobb-Douglas preferences, it is possible to derive the short-run supply of fish as a function of a given stock size (see Section 9.3 in the Appendix).

$$H = \alpha S^\tau \beta L_T. \tag{4}$$

This "short-run catch function" is depicted by the black line in Figure 1. Equation 4 shows that, in the short-run equilibrium, a fraction β of workers is employed in fishing.

In the autarky steady state equilibrium, catch equals the resource growth rate. Therefore, the autarky steady state is characterized by the intersection of the short-run catch function and the resource growth function with a stable steady state resource stock of S_A. The fishery can collapse even in the absence of trade if the parameters of the model change such that $G(S)$ and H do not intersect at any positive stock levels.

2.2 Trade

This section investigates the effect of trade openness on a small country, for which the world market price is exogenous. The pattern of trade depends on the world market price p^* relative to the country's autarky price p_A. Since this paper analyses the effect of exports on the domestic fishery, trade is modelled as an exogenous increase in the resource price $p^* > p_A$.[5]

The exposition below focuses on the case in which the country is in the autarky steady state when it first opens up to trade. However, the same results follow through when a small economy is in a diversified trading equilibrium and experiences an exogenous increase in the price. This exogenous increase in the price could result from a further trade liberalization or from an export demand shock.

2.2.1 Short-term pattern of production and trade

When a country opens up to trade and the world market price for fish exceeds the domestic price, the country specializes in fishing. Catch and exports increase instantly and the stock declines over time.[6]

The instantaneous increase in catch upon opening up to trade is explained by the abrupt switch of the entire country's labour force into the fishing industry.

[5] The country imports fish if $p^* < p_A$. In that case, the fish stock recovers as a result of trade as long as $S > \underline{S}$ when the country opens up to trade.

[6] The country specializes in fishing since the marginal value product of labour in fishing exceeds the marginal value product of labour in manufacturing when the country opens up to trade. The marginal value product of labour in fishing is given by the worker's fishing productivity αS_A multiplied by the price of fish. When the price suddenly increases to p^* and the stock is fixed in the short term, the marginal value product of labour in fishing exceeds the marginal value product in manufacturing, which is fixed at 1.

This is captured by a move from H_A to H_1 in Figure 1. H_1 is on the "specialized catch function" H_S

$$H_s = \alpha L_T S, \tag{5}$$

which is represented by the upward-sloping segment of the red curve in Figure 1.

The country exports fish and imports manufacturing products when it opens up to trade. This is evident from the fact that the country only produces fish but workers consume both products. The stock declines over time, since catch exceeds the resource growth rate once the country has specialized in fishing (e.g. at H_1).

Brander and Taylor (1997*a*)'s findings on the effect of exports on resource stocks yield the first set of hypothesis for the empirical analysis.

Hypothesis 1. *In an open access fishery, an exogenous increase in the price leads to*

(a) an instantaneous increase in harvest and exports and

(b) a smaller resource stock in future periods.

In the long term, three outcomes are possible: A diversified steady state, a specialized steady state (both with a smaller resource stock than under autarky) or the collapse of the fishery. The collapse of the fishery is discussed in the following section. A discussion of the diversified and specialized steady states is deferred to Sections 9.4 and 9.5 in the Appendix.

2.2.2 Fisheries collapse in exporting countries

This section shows that a fishery that is sustainable in autarky can collapse when the country opens up to trade. However, not all fisheries collapse when the country exports fish.

The dynamics leading to the collapse are illustrated by the red line in Figure 1. Given the world market price $p_c > p_A$, the small open economy remains specialized in fishing up to the point at which the stock has declined to $S_c = 1/(p_c\alpha)^{1/\tau}$ and the marginal value product of fishing equals the marginal value product of manufacturing. At this point, the economy could diversify and produce both products. However, even if diversification reduces catch and takes pressure off the resource, S_c cannot be a steady state resource stock. Since resource growth is negative at S_c, the stock continues to decline to zero and the fishery collapses.

Yet, a collapse can only occur if two conditions are satisfied: First, a collapse can only happen if the world market price is high, i.e. $p_c \geq 1/(\alpha\underline{S}^{\tau})$.[7] Second, a collapse is only possible if harvest under specialization H_s exceeds resource growth $G(S)$ for any positive stock level.[8] This is the case if fishing capacity is high relative to the resource growth rate. Advanced fishing technology or a large labour force facilitate a collapse at high world market prices. A detailed analysis of the parameter values which mean a collapse becomes possible under trade is available in Section 9.6 of the Appendix.

Hypothesis 2. *An open access fishery in an exporting country can collapse if the world market price is high and if fishing capacity is sufficiently high relative to the resource growth rate.*

The theoretical model highlights that catch data can inform us about the collapse of a fishery. Harvest is a function of the stock size and when the stock is depleted, harvest is low (see Equations 4 and 5). A very low catch compared to its historical maximum is, thus, indicative of a small stock and a potential collapse of the fishery.

3 Empirical strategy

This section shows how the causal effect of fisheries exports on the probability of a fishery's collapse is estimated. The coefficient estimate for exports is biased downwards in a naive OLS regression of fisheries collapse on exports due to an omitted variable bias: both the probability of collapse and exports critically depend on the underlying fish stock. A lower stock simultaneously increases the probability of collapse while decreasing exports. Yet the size of the underlying fish stock remains unobserved.

[7] This implies that a collapse can only happen if the minimum viable stock size $\underline{S}$ is positive and fish population growth is negative for any stock $S < \underline{S}$. Negative population growth at small stock levels is called "critical depensation". Slow recovery of depleted fish populations (Hutchings, 2000) suggests critical depensation. Moreover, Keith and Hutchings (2012) find evidence for depensation for a subset of species. Fisheries can collapse as a result of trade in a model without critical depensation, as demonstrated by Gars and Spiro (2018) in an Armington trade model.

[8] If this is not the case, the stock shrinks to S_z, where catch under specialization equals resource growth. At this point, the stock cannot decline further since resource growth would exceed catch for any stock $S < S_z$ and the stock would recover. S_z is the specialized steady state stock discussed in Section 9.5 in the Appendix.

To address this endogeneity, the collapse of Japanese fisheries is used as an instrument for fisheries exports in countries that do not share fish stocks with Japan. The collapse of a Japanese fishery is associated with a significant reduction in Japanese catch. Since Japan is a large market for fishery products, the Japanese collapse raises the world market price and export demand in other countries. Due to the increase in exports and the resulting higher fishing pressure, the fishery can collapse in the exporting country. The empirical strategy ensures that trade is the only channel through which a collapse in Japan can affect the collapse of a fishery in another country.

3.1 Estimating equation

This paper estimates the effect of an increase exports on the probability of a fishery's collapse.[9] The dependent variable Collapsed_{ikt} is a dummy variable, that takes the value of 1 if fish species i has collapsed in country k in year t. This paper uses a common approach (see e.g. Worm et al., 2006; Costello, Gaines and Lynham, 2008) and defines a fishery as collapsed if catch from a wild-capture fishery is below 10 percent of the maximum catch recorded since 1950.

The collapse of fisheries has to be inferred from catch data since scientific stock assessments are sparse and do not cover a representative sample. The RAM Legacy stock assessment database covers a time series of 305 national stock assessments.[10] Less than 50 of these assessed stocks can be matched with trade data at the country-species level.[11] Moreover, assessed fish stocks are not representative (Froese et al., 2012), since assessments are conducted on high value, resilient and often well-managed stocks in the US, Canada, Australia and New Zealand. An analysis relying on assessed stocks would not be able to capture the effect of trade on fisheries in developing countries, which are major exporters of fishery products

[9] Even though this paper's identification strategy is based on the idea that an increase in the price (and hence in catch) leads to an increase in exports, this paper does not use price or catch data as regressors for two reasons. First, the identification relies on a country being open to trade and exporting a particular species. This can only be guaranteed through the use of export data. Second, the majority of price data is estimated and hence of poorer quality than the export data.

[10] The database also covers 195 fish stocks with multinational stock assessments. The latter cannot be used for the analysis since most of those fisheries include stocks which may be shared with Japan. Moreover, it would not be possible to match the multinational stocks to country-level export data.

[11] Trade data at the species level are not available for all species.

(FAO, 2016*b*).

The variable Collapsed_{ikt} is unlikely to systematically misrepresent the depletion of fisheries. For example, Froese et al. (2012) have shown that trends in catch data are consistent with trends in biomass data from stock assessments. Moreover, this paper conducts a range of robustness checks - some using data from stock assessments - all of which suggest that the findings are not driven by a mis-measurement of fisheries collapse (see Sections 6.2 and Section 10.3 in the Appendix).

In the dataset used for the analysis, fisheries are observed up to the year in which they collapse. Once the fishery has collapsed, the stock is very small. Hence the catch in all subsequent years is very small, and it follows therefore that exports are low as well. In this case, the direction of causality runs from a collapse of a fishery, through low catches, to minimal exports. As a result, observations from fisheries which are collapsed cannot be used to understand whether exports lead to collapse. Therefore, observations from collapsed fisheries are not used in the analysis.

It is possible for a collapsed fishery to recover, and such fisheries reappear in the dataset. However, those fisheries may be more vulnerable to a future collapse. Therefore, the regression includes the dummy variable "Prev. Collapsed_{ikt}", which takes a value of 1 if the fishery has collapsed in the past. Fisheries that do not collapse are observed until the end of the sample period in 2006.

This paper models the probability of a fishery's collapse as a function of the natural logarithm of the export quantity of species i in country k in year $t-1$, of a previous collapse of the fishery (Prev. Collapsed_{ikt}), of region-year fixed effects (γ_{rt}), country fixed effects (γ_k), species fixed effects (γ_i) and an error term (ϵ_{ikt}). The analysis is based on the following estimating equation

$$\text{Collapsed}_{ikt} = \beta_0 + \beta_1 \ln(\text{Exports})_{ikt-1} + \beta_2 \text{Prev. Collapsed}_{ikt} + \gamma_{rt} + \gamma_i + \gamma_k + \epsilon_{ikt}. \tag{6}$$

Since an increase in exports will only manifest itself as a reduction in the fish stock or a collapse in future periods, the baseline specification uses exports in year $t-1$ as the regressor. This captures the short-term effect of exports on the probability of a collapse in the following period. Long-term effects and dynamics are discussed and estimated in Sections 6.1 to 6.2. This paper uses data on export quantities rather than export values in order to net out price effects.

Region-specific variation in climatic and environmental factors is captured by region-year fixed effects. Those fixed effects control for all factors that raise the probability of a collapse equally for all species in one region in a particular year and capture time trends in the rate at which fisheries collapse. A region is defined as either the Atlantic Ocean including the Mediterranean Sea or the Pacific Ocean and Indian Ocean.

Species fixed effects capture all time-invariant species characteristics that could affect the probability of a collapse. Those characteristics include the species' fecundity and growth rate. Country fixed effects control for time-invariant country characteristics, such as the preference for fish. The results follow through with country-species fixed effects as demonstrated in Table 13 in the Appendix.

Since the dependent variable is binary, this paper estimates a linear probability model as advocated by Angrist and Pischke (2009). There are several reasons to choose a linear probability model over a nonlinear binary dependent variable model such as logit or probit. First, Angrist and Pischke (2009) point out that 2SLS models estimate average local treatment effects even if the dependent variable is binary. Second, linear probability models require fewer functional form and distributional assumptions and they offer a straightforward interpretation of the coefficient estimates as marginal effects. Finally, the estimated marginal effects from IV probit regressions with fewer fixed effects (either $\gamma_{rt} + \gamma_i$ or $\gamma_{rt} + \gamma_k$) were are almost identical to the marginal effects in a linear probability model. Considering the difficulties in implementing a non-linear model with a large number of fixed effects and instrumental variables, this paper only displays results from a linear probability model.

The sample only includes observations with strictly positive trade flows and the analysis focuses on the intensive margin of exports. In other words, this paper investigates whether an increase in the volume of fisheries exports raises the probability of a fishery's collapse. The question whether countries start exporting and how this affects their fish stocks is not analysed in this paper since data on zero trade flows are incomplete. Moreover, this paper does not look at the effect of trade on importing countries where stocks could recover, at least temporarily, when the country opens up to trade (Brander and Taylor, 1997*a*; Copeland and Taylor, 2006).

The identification strategy assumes that there are no substitution effects across species. Substitution effects may occur since the collapse of a Japanese fishery is associated with an increase in the price. This could raise (export) demand for substitute species, making a collapse of substitutes more likely. In the case of substitution across species, the coefficient estimate of β_1 has to be considered a lower bound for the true effect. Section 10.2 discusses this in detail and shows that there is no evidence of substitution effects.

3.2 OLS estimates are biased downwards

An OLS regression would underestimate the effect of exports on fisheries collapse. This holds true even if we only observe fisheries up to the point in which they collapse. The downward bias results from the fact that both exports in period $t-1$ and the dependent variable are correlated with the stock size S_{t-1}, which is not observed. When a fish stock is overfished and S_{t-1} is low, the stock is more likely to collapse in period t. This may be due to the fact that the catch exceeds resource growth in period $t-1$ or due to a small stock's reduced resilience to environmental factors that could cause a collapse. At the same time, a small stock S_{t-1} implies a small catch and low export volumes in period $t-1$.

3.3 Collapse of Japanese fisheries as an instrument

To address this endogeneity, the collapse of Japanese fisheries is used as an instrument for fisheries exports in countries that do not share stocks with Japan.

The instrument is species-year specific and the analysis exploits substantial variation in Japanese fisheries collapse across time and species. Japan experiences a drastic increase in the collapse of fisheries during the sample period. The proportion of collapsed fisheries in Japan increased from 14 percent in 1976 to 32 percent in 2006. Species collapse throughout the sample period and almost all categories of species are affected.[12] Figure 4 shows the percentage of collapsed species in Japan and reveals variation across time and species (groups).

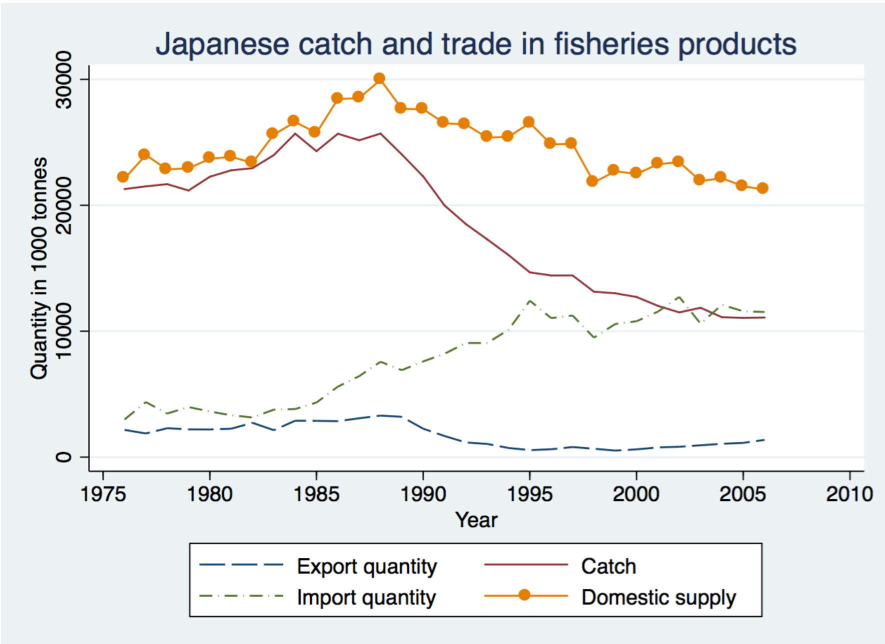
This paper argues that the collapse of species i in Japan has a strong influence on exports of species i in other countries, since Japan is both a large supplier and consumer of seafood. When Japanese catch declines as a result of the collapse, Japan sources more seafood products on foreign markets. The resulting increase in Japanese import demand raises the world market price for species i, spurring exports of species i in the rest of the world. Therefore, a collapse in Japan generates

[12] Column 3 of Table 8 in the Appendix shows the number of individual species that collapse in Japan during the sample period by species category.

an export demand shock in other countries. The data confirm that this mechanism is at work.

Japan was the largest producer of fishery products until the late 1980s and caught around 18% of the world's marine catch at the beginning of the sample period in 1976 (see Figure 2). Yet this masks variation across species categories and species. Figure 3 shows that Japan used to supply the majority of the world's sea urchins, sea cucumbers and other miscellaneous aquatic animals, as well as almost half of the molluscs. Japan's contribution to global supply of marine catch hovered between 15% to 20% until the late 1980s, again with ample variation within marine species. Some marine species are caught predominately in Japanese waters whereas others are not caught by Japan at all.

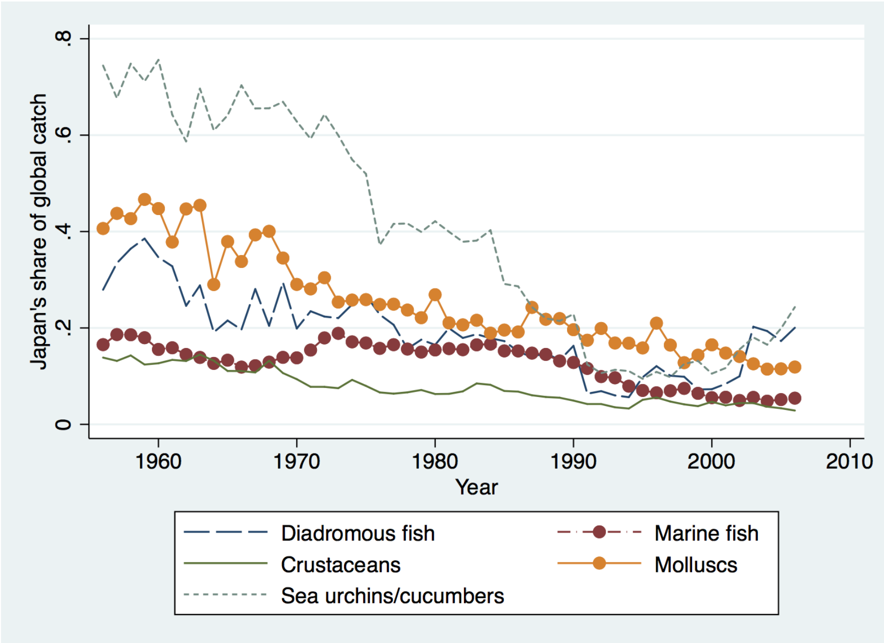
Figure 2: Japanese landings and trade in fishery products



Total exports, imports, landings and domestic supply of marine fish and other fishery products, excluding freshwater fish. Domestic supply is defined as production-exports+imports+stock changes. The underlying data are from the FAO food balance sheets.

Japan's total production of fishery products declined over the course of the sample period (Figure 2), but an increase in imports guaranteed a stable supply of fishery products in Japan. The green dashed line in Figure 2 shows the rapid growth in fisheries imports, which made Japan the second largest importer of seafood products from 1987 onwards. Due to this increase in imports, the domestic

Figure 3: Japan's share of global catch by species category



Author's calculation based on data from the Sea Around Us catch database

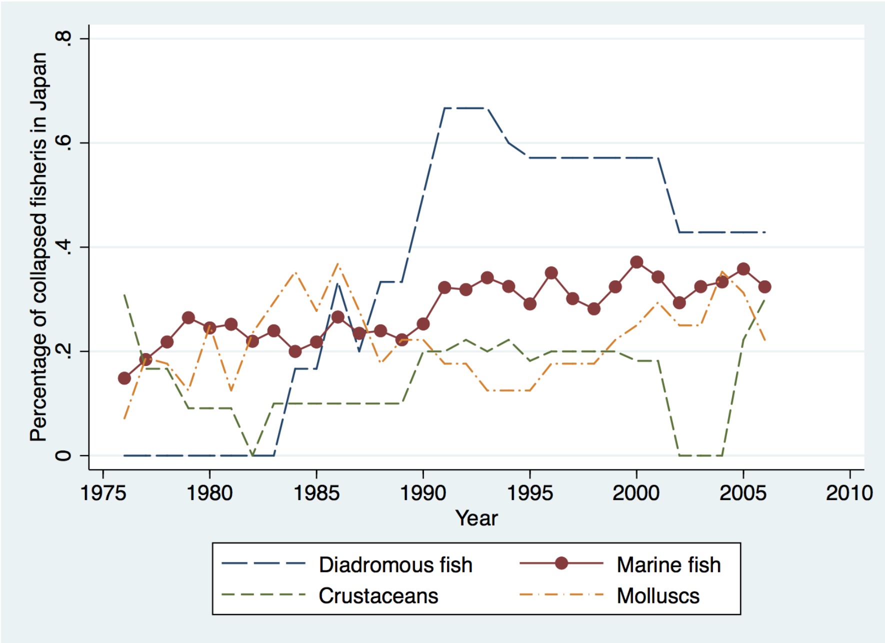
supply (defined as production-exports+imports+stock changes) of fishery products remained relatively stable as demonstrated by the yellow line in Figure 2. Japan remains the second largest market for seafood products after China.[13]

Detailed price data corroborate the idea that the collapse of a Japanese fishery raises the price of the respective species in the rest of the world and thus leads to an export demand shock. Table 1 shows that a collapse of species i in Japan is associated with an increase in the price of species i in exporting countries by 6 percent.[14] This increase in the world market price raises exports in the rest of the world and the first stage regression, which is discussed in Section 5.2, captures this effect. As discussed, about two thirds of the price data are estimated, therefore the remainder of the analysis focuses on export data to capture the effect of an

[13]This paper does not use the collapse of Chinese fisheries as an instrument for exports, even though China has become the largest market for seafood products in the late 1980s, since Chinese landings statistics are likely to be overreported (see e.g. Watson and Pauly, 2001; Pauly and Froese, 2012). The US is another large market for fisheries products, but the collapse of fisheries in the US is a weak instrument. In a robustness test, Japanese preferential import tariff at the species level were used as a second instrument, but they are not significantly related to exports in the first stage regression due to low time variation.

[14]Country-species-year level price data are from Swartz, Sumaila and Watson (2012), who collect a comprehensive dataset of ex-vessel prices and estimate missing price data.

Figure 4: Percentage of collapsed fisheries in Japan by species category



Author's calculation based on data from the Sea Around Us catch database.

exogenous increase in price on the collapse of fisheries.

Table 1: A collapse in Japan raises the ex-vessel price in exporting countries

	(1) Ln (Price)$_{ikt}$
Collapse in Japan	0.060*
	(0.035)
Country FE, Species FE, Region-Year FE	Yes
No. of clusters	108
Observations	8880

Standard errors (clustered at the species level) in parentheses. The sample covers the same observations as the baseline regression.
* p<0.1, ** p<0.05, *** p<0.01

3.4 Exclusion restrictions are satisfied

The instrument is only valid if trade is the only channel through which a Japanese collapse affects a collapse in the exporting country. In order to guarantee that the exclusion restrictions are satisfied, this paper only studies fisheries that are not shared between Japan and the exporting country. If fish stocks are shared, the collapse of a Japanese fishery would be directly related to a fisheries collapse in the exporting country. Moreover, the empirical strategy ensures that the collapse in Japan and the exporting country are not driven by common shocks.

Since neighbouring countries are likely to share fish stocks, all countries with Exclusive Economic Zones (EEZ)[15] adjacent to Japan are excluded from the sample. The sample does not include Russia, North and South Korea, China, Taiwan, the Philippines and the Northern Mariana Islands. Excluding neighbouring countries also reduces the risk of ecosystem linkages between Japanese fisheries and fisheries in exporting countries confounding the results.

Some species migrate large distances and therefore stocks of migratory species could plausibly be fished by both Japan and another country a long way from Japan. Data from this second country would not be excluded from the sample if it is not one of Japan's neighbours. Therefore, the sample does not include fish species which are known to migrate large distances (e.g. tunas) nor species with extensive distributions in the high seas. To be precise, the analysis excludes highly migratory fish species listed in Annex 1 of the UN Convention of the Law of the Sea (UN General Asssembly, 1982) as well as fish species with ranges in the high seas and all straddling fish stocks[16] in the area surrounding Japan (FAO fishing area 61).

Moreover, this paper uses a collapse in Japan in year $t-1$ as an instrument. Using the lag of the Japanese collapse further reduces the risk that unobserved shocks, such as short-term fluctuations in climatic conditions like El Niño, simultaneously affect fisheries in Japan and in the exporting country.

Major climatic events are picked up by region-year fixed effects. Hence, they do not violate the exclusion restrictions. Species fixed effects capture all species-specific biological factors, such as growth rates or age-at-maturity which determine a species' innate proneness to collapse.

[15]EEZs were formally established with the UN Convention on the Law of the Sea, which grants coastal states exclusive rights to explore marine resources within an area of up to 200 nautical miles (370 km) from a country's coast.

[16]A list of the latter two groups is based on Maguire et al. (2006). Straddling fish stocks are stocks which occur both within a country's EEZ and beyond it.

3.5 Why did Japanese fisheries collapse?

Anecdotal evidence suggests that the collapse in Japan is not driven by shocks that could also affect exporting fisheries in the sample. Makino (2011) highlights that most Japanese fisheries collapse as a result of high demand for fishery products (indeed, FAO data show that per capita seafood consumption in Japan was about 7 times the world average in 1976), overcapacity in the Japanese fishing industry and inadequate fisheries management. The collapse is mostly driven by domestic factors and often precedes the collapse in other countries. Where available, anecdotal evidence suggests that overfishing was responsible for the collapse of Japanese fisheries.[17]

4 Data and summary statistics

This section explains the construction of the novel country-species level dataset on trade in fishery products and fisheries collapse and presents summary statistics.

4.1 Data

A fishery's collapse is inferred based on catch data from the Sea Around Us catch database (Pauly, Zeller and Palomares, 2020). The database maps species level catch to each country's Exclusive Economic Zone using ancillary information on the distribution of commercially exploited species and fishing access agreements. The data are described in detail in Watson et al. (2004).[18] The Sea Around Us Catch Database contains species-level information on catch from 1950 to 2006.

Disaggregate fisheries trade data for the years 1976 to 2006 are from the FAO Fisheries Commodities Production and Trade Statistics. The trade data are, for the first time, matched with catch data at the country-species-year level. The matching is based on the species' common name listed in the trade data. The analysis only makes use of export data that clearly identify the exported species,

[17] See Makino (2011) for evidence on the collapse of sandeels, chub mackerels, sand fish, snow crab, Makino (2010) for evidence on Walleye pollock, Matsukawa et al. (2008) for manila clam, Nagai et al. (1996) for growth-overfishing of Spanish mackerel. Moreover, Uchino et al. (2004) documents that the decline in abalone abundance was at least partly due to overfishing.

[18] This paper uses the same data as Swartz, Sumaila and Watson (2012). Those data were made available to me by the Institute for the Oceans and Fisheries at UBC and I thankfully acknowledge their cooperation.

(e.g. haddock or Atlantic cod). Those data can be matched one-to-one to the species-level catch data. Some export statistics are reported in aggregate categories applying to several species (e.g. "mussels"). Since it is not possible to know which mussel species are exported, those export data are not used for the analysis.

Export data have to be aggregated to the species level since raw exports data distinguish between fresh and processed exports. For example, exports of cod are broken down into three categories: exports of fresh and chilled cod, exports of frozen cod and exports of cod meat. Exports of cod at the country-species level are the sum of exports in those three categories.[19] The same aggregation is used for all other species.

The analysis dataset is an unbalanced panel covering 93 countries and 109 different marine species. This paper uses data from coastal countries not neighbouring Japan. The sample spans all countries shaded in red or blue in Figure 5. Column 2 of Table 8 in the Appendix shows the number of distinct country-species combinations in the sample by species group.

4.2 Summary statistics

The summary statistics reveal that an increase in fisheries exports coincides with an increasing prevalence of fisheries collapse in exporting countries. Moreover, as will become apparent, the biggest exporters also have the highest proportion of collapsed fisheries at the end of the sample period.

Exports of fishery products grew by 277 percent over the sample period. The total export quantity of fishery products in the sample used for this study increased from 1.1 million tonnes in 1977 to 4.2 million tonnes in 2006 (see Figure 5).[20]

This export growth coincides with an increasing prevalence of fisheries collapse in exporting countries. The red line in Figure 5 shows that the proportion of collapsed fisheries increased from 7.8 percent in 1976 to 25 percent in 2006. Fisheries collapse throughout the sample period. The green line in Figure 5 indicates that between 2 and 8 percent of the fisheries collapse every year. The summary statistics in Table 2 show that 4.7 percent of the observations represent collapsing fisheries, i.e.

[19] Some species are also exported in dried form. Due to a lack of systematic conversion rates for all fish species, it is not possible to convert the dry weight to wet weight. Hence, dry weight is treated the same way as wet weight.

[20] Total exports of all fishery products, including exports of species which are not in the sample grew by almost 400 percent over the same time period.

fisheries in the year they collapse. Most of the collapsed fisheries are cod, hake and haddock fisheries, as demonstrated by Table 8 in the Appendix. This holds true for both the exporting countries and fisheries in Japan.

Table 2: Summary statistics

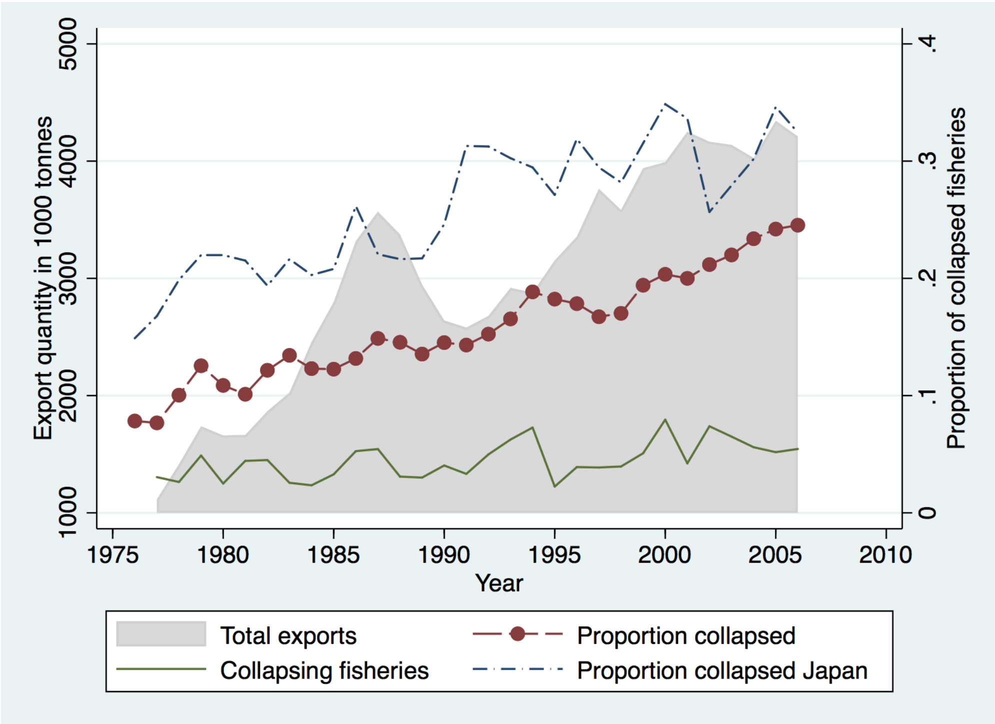
	(1) Mean	(2) Overall Sd.	(3) Between Sd.	(4) Within Sd.
Collapsed	0.047	0.211	0.154	0.189
Export quantity (lag)	9.983	38.877	24.225	22.713
Export quantity (lag, ln)	6.564	2.665	2.648	1.109
Catch share (lag)	0.104	0.305	0.208	0.191
Collapsed Japan (lag)	0.117	0.321	0.229	0.238
Observations	8880	8880	8880	8880

Between Sd: Standard deviation between country-species combinations
Within Sd: Standard deviation within country-species combinations

Fisheries collapse is more prevalent in Japan than in the rest of the world. The green dashed line in Figure 5 reveals that the proportion collapsed fisheries in Japan surges from 14 percent in 1976 to 32 percent in 2006. Japanese stock assessments confirm the poor state of Japanese stocks. 43 out of the 90 assessed stocks within Japan's EEZ were categorized as being at low levels in 2007 (Makino, 2010).

Countries with high exports are also the ones with the highest proportion of collapsed fisheries in 2006. Such a pattern can easily be seen by comparing Figure 6, which shows the proportion of collapsed fisheries in 2006, with Figure 7, displaying average country-level exports. Average exports are defined as $(\sum_{t=1976}^{T=2006} \sum_{i \in I} \text{Exports})/31$, where I is the set of all fisheries within a country in the sample.

Figure 5: Fisheries collapse and export quantities in the sample



Note: Collapsing fisheries are fisheries the year in which they collapse.

Figure 6: Proportion of collapsed fisheries at the end of the sample period

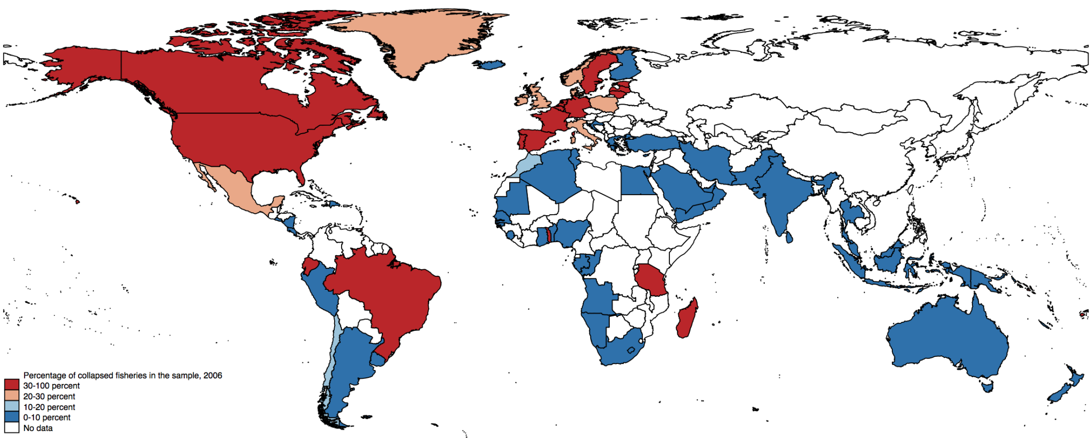
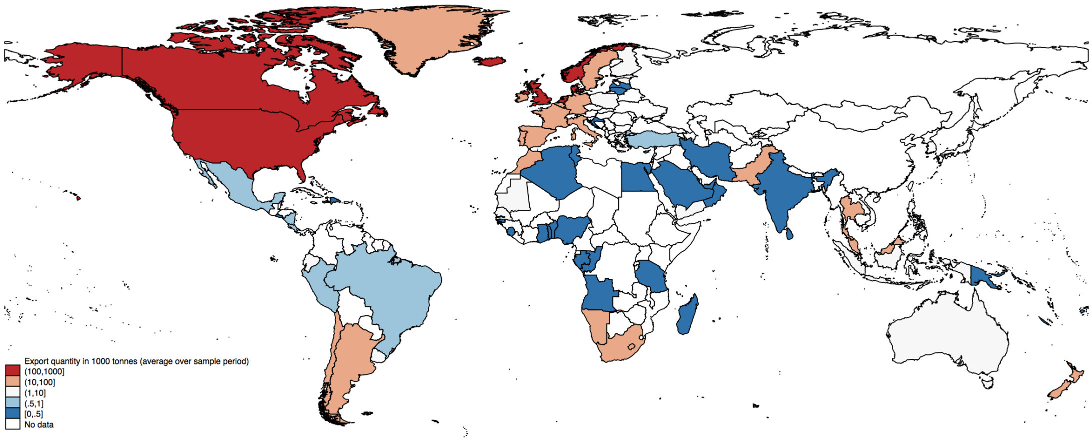


Figure 7: Countrys' annual total export quantity, averaged over a 30 year sample period



5 Results: Exporting leads to the collapse of fisheries

The results in this section show that exporting significantly raises the probability of fisheries collapse the subsequent year. The instrumental variable estimation addresses a downward bias in the OLS regression. Only fisheries that are not regulated via catch share programs collapse as a result of exports.

5.1 Benchmark OLS regression

The results from the OLS regression presented in this section reveal a downward bias in the coefficient estimate. The coefficient estimate for the export quantity in Column 1 of Table 3 suggests that an increase in exports by one percent reduces the probability of a fishery's collapse in the following period by 0.003 percentage points. The negative relationship between exports and the fishery's collapse is counterintuitive but, as discussed in Section 3.2, it may be due to a downward bias of the coefficient estimate. The results from the instrumental variable regressions in the next sections confirm this.

Table 3: OLS and baseline results

	(1)	(2)	(3)
Dependent variable:	Collapse	Exports	Collapse
Export quantity (lag, ln)	-0.003**		0.119**
	(0.002)		(0.049)
L.Col. Japan		0.222***	
		(0.069)	
Controls	Yes	Yes	Yes
Fixed effects: γ_{rt}, γ_i, γ_k	Yes	Yes	Yes
1st stage F-Stat			10.366
Anderson-R. p-value			0.004
No. of clusters	108	108	108
Observations	8880	8880	8880

Standard errors (clustered at the species level) in parentheses. The p-value of the Anderson and Rubin (1949) test (Anderson-R. p-value) provides weak instrument robust inference for the coefficient estimate for the export quantity.
* p<0.1, ** p<0.05, *** p<0.01

5.2 Assessment of the instrument

The collapse of fisheries in Japan is a sufficiently strong instrument for exports from countries not sharing stocks with Japan. The first stage regression (Column 2 of Table 3) shows that the collapse of a Japanese fishery is associated with an increase in exports of the same species from other countries by 22 percent. Moreover, the Kleibergen-Paap first stage F-statistic[21] of 10.4 indicates that the instrument is strong based on Staiger and Stock (1997)'s definition.[22]

This paper reports weak instrument robust hypothesis tests for all regressions in addition to the standard hypothesis tests. The penultimate column of all results tables in this paper is labelled "Anderson-R. p-value" and shows the p-value for Anderson and Rubin (1949)'s test of structural parameters, which is fully robust to weak instruments. When this p-value is below 0.1, the coefficient estimate for the export quantity is significant even when the instruments are weak. This is relevant for some of the robustness tests with a first-stage F-Statistic below 10. In

[21] Since standard errors are clustered, this paper reports the Kleibergen-Paap F-statistic as the relevant first stage F-statistic in all results tables.

[22] According to this definition, an instrument is weak if the first stage F-statistic is below 10. A more formal test by Stock and Yogo (2005) shows that it is possible to reject the null-hypothesis that the asymptotic bias of the 2SLS bias exceeds 15% of the OLS bias.

this case, the coefficient estimate for β_1 should be considered a lower bound of the true effect of exports.

5.3 IV results: Exporting leads to the collapse of fisheries

The baseline instrumental variable results reveal that exports have a large effect on the collapse of fisheries. Column 3 of Table 3 shows that an increase in exports by one percent raises the probability of a fishery's collapse in the following year by 0.119 percentage points. The effect is large: An increase in logged exports by one standard deviation raises the probability of a collapse by 29 percentage points.

Are the estimates realistic in light of the observed trend in fisheries collapse over the sample period? An answer to this question requires more insights into the development of exports during the sample period. Exports in the median fishery grew by 53 percent between 1991 and 2006 (half of the sample period). According to the estimates, this export boost raised the probability of a collapse by around 6 percentage points. Since the proportion of collapsed fisheries increased by 10 percentage points during that time, the predicted increase in the probability of a collapse is equivalent to 62 percent of the observed cases of fisheries collapse. However, these numbers have to be interpreted with caution since they extrapolate an estimated short-term effect over a time period of 15 years.

The findings also provide tentative evidence for serial fisheries depletion due to trade. Based on the results from the reduced form regression, the collapse of a Japanese fishery raises the probability of a collapse in a non-neighbouring country by 2.6 percentage points. This paper only captures one link in a potential chain of resource collapse. If trade leads to serial fisheries depletion beyond this first link, it could be more damaging for the oceans than the estimates in this paper suggest.

Hypothesis 1 highlights that exports lead to a collapse of fisheries in exporting countries due to an increase in catch. To show this empirically, it is possible to use the same empirical approach and the same sample as in the baseline regression but use the log of catch as a regressor instead of the log of exports. The results reveal that an increase in catch by one percent raises the probability of a collapse in the following period by 0.23 percentage points (see Table 9 in the Appendix). This coefficient estimate is statistically significant based on weak instrument robust inference.

5.4 Only fisheries without catch share programs are affected

Theory indicates that exporting can lead to a collapse of open access fisheries. When fisheries are well-managed, harvest and exports are likely to respond less to a demand shock from Japan. Consequentially, well-managed fisheries are not depleted when the country exports fish (Brander and Taylor, 1997*b*). This section provides suggestive evidence that exports only raise the probability of a collapse if fisheries are not regulated via catch share programs.

To analyse how fisheries management affects the relationship between exports and fisheries collapse, this paper splits the sample into catch share fisheries and fisheries that are not regulated via catch share programs.[23] Catch share programs are fisheries management tools that allocate secure fishing rights to individual entities. Most of the catch share programs are individual transferrable quotas (ITQs) or similar quota-based programs allocating fishing rights to a proportion of a total allowable catch. But a small proportion of catch share programs are area-based and allocate the privilege to fish in specific areas to groups or individuals. These programs are called Territorial Use Rights for Fishing programs (TURFs). Fisheries without catch share programs may be subject to other regulatory measures, but there are no global datasets recording these measures.

In the sample of catch share fisheries, the first stage regression reveals that a collapse in Japan does not lead to a significant increase in exports. Moreover, the results from the second-stage regression in Column 1 of Table 4 show that exports do not spur a collapse of catch share fisheries. However, the weak correlation between the instrument and exports in the sample of managed fisheries implies that the second-stage regression results may be biased downwards and have to be interpreted with caution.

Exports raise the risk of a collapse for fisheries without catch share programs: the probability of a collapse increases by 0.13 percentage points as exports increase by one percent (Column 2 of Table 4). Those results are based on a sample including fisheries that are not regulated via catch share programs in year t but adopt those programs later on. In a sample of fisheries that are never regulated via catch share programs, an increase in exports by one percent raises the probability of a collapse

[23] The analysis makes use of data on catch share programs from the Environmental Defense Fund (EDF). The author contacted the respective fisheries management authorities and used information from government websites and scientific articles to complete missing information on the year in which a catch share program was adopted.

Table 4: Only unmanaged fisheries collapse as a result of exports

	(1)	(2)	(3)	(4)
Sample:	Catch share	No catch share	No catch share	All
Export quantity (lag, ln)	-0.093	0.133**	0.108***	0.113**
	(0.066)	(0.055)	(0.034)	(0.046)
L. ln(Exports) × L.Catch share				0.008
				(0.033)
L.Catch share				-0.132
				(0.283)
Controls	Yes	Yes	Yes	Yes
FEs γ_{rt}, γ_i, γ_k	Yes	Yes	Yes	Yes
1st stage F-Stat	1.910	10.250	13.073	10.076
Anderson-R. p-value	0.083	0.004	0.002	0.006
No. of clusters	47	108	94	108
Observations	992	7885	6452	8880

Dependent variable: Collapsed. Standard errors (clustered at the species level) in parentheses. The p-value of the Anderson and Rubin (1949) test (Anderson-R. p-value) provides weak instrument robust inference.
* $p<0.1$, ** $p<0.05$, *** $p<0.01$

by 0.11 percentage points (see Column 3).

Results from a sample of fisheries without catch share programs represent a conservative estimate of the effect on open access fisheries. The coefficient estimates in Columns 2 and 3 of Table 4 present the average effect of exports on open access fisheries and fisheries subject to regulatory measures other than catch share programs. The effect of exports is likely to be lower than 0.11 for regulated fisheries and higher for open access fisheries.

The results provide suggestive evidence that quotas shield fisheries from potentially negative effects associated with exporting. However, it is possible that catch share and unregulated fisheries differ systematically in their underlying characteristics. Hence, the benefits that are associated with catch share programs may not translate to fisheries that are currently not regulated via catch share programs.

In an attempt to address this concern, Table 4 also presents results for the full sample and includes an interaction term between exports and the catch share dummy variable as a regressor. The collapse in Japan interacted with the catch share dummy variable is used as a second instrument.[24]

[24] The second instrument is valid if the adoption of a catch share program for species i in country

The estimates in Column 4 of Table 4 show that an increase in exports does not significantly raise the probability of a collapse in catch share fisheries. However, the results confirm that exports significantly raise the probability of a collapse in fisheries without catch share programs by 0.11 percentage points. The coefficient estimate is of the same order of magnitude as the baseline estimate and indicates that the findings in the baseline regression are mostly driven by fisheries without catch share programs.

The results presented in this section imply that sustainable fisheries management is necessary to guarantee long-term benefits from fisheries in exporting countries. When fisheries are regulated through catch share programs, exporting does not seem to harm fisheries.

6 Dynamics

While the baseline regression analyses the short-term effect of exports on the collapse of fisheries, this section shows that exporting significantly raises the probability of a collapse in the medium and long term. The medium and long term effects are important to investigate since the stocks may be eroded gradually due to exports.

6.1 Maximum historical exports and longer lags

The theoretical model in Section 2 predicts a temporary spike in catch and exports as a result of the exogenous increase in the price. Even if the price stays high, exports decline over time as the stock declines. The effect of this temporary spike in exports can be captured empirically regressing the collapse of fishery ik in year t on fishery ik's maximum historical exports recorded up to year t. The variable is defined such that fishery ik's maximum historical exports increase over time as the fishery's exports increase. Once the fishery's exports have reached a peak, the variable stays constant. This approach is agnostic about the time lag between the increase in exports and a fishery's collapse. It is well suited to translate the medium- and long-term effects of exports on a collapse from theory to data, since the speed at which a fishery collapses depends on the fishery's characteristics.

k is exogenous and not affected by a collapse of species i in country k. Table 10 in the Appendix shows that the collapse of a species in period $t-1$ does not make the adoption of a catch share program in period t more likely. The table shows a precisely estimated null-effect.

The results confirm that exporting leads to fisheries depletion in the medium to long-term. Column 1 of Table 5 shows that an increase in maximum historical exports by 1 percent raises the probability of a fishery's collapse by 0.11 percentage points. The coefficient estimate is statistically significant based on weak instrument robust inference.

Longer lags of exports can shed further light on the dynamic relationship between exports and the collapse of fisheries. Column 2 of Table 5 shows that an increase in exports in period $t-2$ is estimated to raise the probability of a fishery's collapse in period t by 0.15 percentage points. This estimate is slightly higher than the short-term effect estimated in the baseline regression.[25]

Unfortunately, it is not possible to estimate a distributed lag model, since this would require an IV for every lag of exports. Using several lags of the collapse in Japan as instruments yields weak IVs due to the high correlation between the different lags of the collapse in Japan. However, the dynamics can be captured by the dynamic panel data model presented in the following section, which uses the best available stock data and shows that higher exports lead to smaller fish stocks.

6.2 Biomass data: Exporting reduces stock biomass

This section uses biomass data to capture both the short-run and long-run effects of exports on fish stocks. The theoretical model in Section 2 shows that the stock in any period is a function of the stock in the previous period, of resource growth and catch. These dynamics can be modelled empirically using biomass data. However, this requires a different empirical strategy. This section uses a dynamic panel data model to explain stock biomass as a function of past stock biomass and exports.

The estimation is based on biomass data from the RAM legacy stock assessment database (Ricard et al., 2012),[26] where available. Due to the sparsity of stock assessments, these data have are supplemented with estimates of stock biomass from Costello et al. (2016).[27] The results show that exporting is associated with a

[25] This paper does not find a significant effect of exports in period $t-3$ on a fishery's collapse in period t (see Column 3 of Table 5). Exports in period $t-4$ are estimated to raise the probability of a collapse in period t by 0.14 percentage points. In all of those regressions, the collapse of a Japanese fishery in period $t-l$ is used an instrument for exports in period $t-l$.

[26] If one country hosts several stocks of one species along different parts of their coastline, the RAM legacy database may provide several stock assessments for one country. In that case, the data are aggregated to the country-species level and matched with country-species-level export data.

[27] I am very grateful to Chris Costello and Tyler Clavelle for access to these data. The estimates

Table 5: Different lags of exports

	(1) Collapsed	(2) Collapsed	(3) Collapsed	(4) Collapsed
Ln(Max. Exp. up to t)	0.150*			
	(0.078)			
L2.ln(Exports)		0.149**		
		(0.061)		
L3.ln(Exports)			0.107	
			(0.113)	
L4.ln(Exports)				0.139
				(0.125)
IV	L.Col. Japan	L2.Col. Jap.	L3.Col. Jap.	L4.Col. Jap.
1st stage F-Stat	4.004	6.550	2.111	1.854
Anderson-R. p-value	0.005	0.001	0.136	0.040
No. of clusters	112	105	102	101
Observations	11256	8330	7821	7352

Standard errors (clustered at the species level) in parentheses. The p-value of the Anderson and Rubin (1949) test (Anderson-R. p-value) provides weak instrument robust inference.
* p<0.1, ** p<0.05, *** p<0.01

reduction in stock biomass and confirm that exports can have a detrimental effect on fish stocks.

6.2.1 An alternative empirical strategy to capture dynamics

The dynamic effect of exports on fish stocks can be modelled in more detail using biomass data. This section uses a dynamic panel data model in which the dependent variable is the natural logarithm of stock biomass of fish species i in country k in year t, $ln(S_{ikt})$. Based on a simplified version of the resource dynamics explained in Section 2, current stocks are a linear function of the natural logarithm of stocks in period $t-1$, $ln(S_{ik,t-1})$ and of the natural logarithm of the export quantity in period $t-1$, $ln(\text{Exports})_{ik,t-1}$.

This yields the estimating Equation 7, in which the error term consists of a country-species-specific time-invariant component η_{ik} and the time-varying com-

of stock biomass are based on catch statistics, fish species' life history data and a structural fisheries modelling approach.

ponent ϵ_{ikt}. The empirical model includes year fixed effects γ_t and controls for fisheries management via catch share programs, as represented by the dummy variable "Catch share$_{ikt-1}$".

$$ln(S_{ikt}) = \alpha_1 ln(S_{ikt-1}) + \alpha_2 ln(\text{Exports})_{ikt-1} + \alpha_3 \text{Catch share}_{ikt-1} + \gamma_t + \eta_{ik} + \epsilon_{ikt} \quad (7)$$

The short-term effect of exports on biomass is captured by the coefficient α_2 in Equation 7. Based on the theoretical model presented in Section 2 and hypothesis 1, an increase in exports in period $t-1$ is associated with a reduction in stock biomass in period t.

The long-term effect of exports on biomass can be calculated as $\alpha_2/(1-\alpha_1)$. This long-term effect captures the effect of an increase in exports in period $t-1$ on biomass in all future periods through a change in biomass in period t.

Equation 7 is estimated using an Arellano-Bond estimator. The Arellano-Bond model uses the first difference of Equation 7 to eliminate the time-invariant components of the error term, η_{ik}. A consistent estimator is obtained using 10 lags of $ln(S_{ikt-1})$, 3 lags of $ln(\text{Exports})_{ikt-1}$, and 3 lags of Catch share$_{ikt-1}$ as instruments for the first difference equation.[28] Due to the availability of alternative instruments, it is not necessary to use the collapse of Japanese fisheries as an instrument in this section.

The analysis makes use of a two-step estimator of the covariance matrix with a Windmeijer (2005) finite sample correction. The standard errors are robust to any form of heteroskedasticity and autocorrelation within panels. The standard errors for the long-term effect are calculated using the delta method.

6.2.2 Results: Exporting reduces stock biomass

The results reveal that exporting significantly reduces stock biomass, both in the short term and in the long term.[29] The short-term effect is captured by the

[28]The instrument matrix is collapsed, as suggested by Roodman (2009), to reduce instrument count, avoid biased coefficient estimates and misleadingly small standard errors.

[29]The usual specification tests suggest that the model is correctly specified. The Arellano-Bond test shows that the null-hypothesis of second-order serial autocorrelation in the first-differenced error term can be rejected. The p-value of the test is shown in the third but last row of the results table. Moreover, the p-value for the Hansen test, displayed in the penultimate row of Table 6, shows that the null-hypothesis of valid moment conditions cannot be rejected.

Table 6: Dynamic model for the effect of exports on fisheries collapse

	(1) Ln(Biomass)
L.Ln(Biomass)	0.573***
	(0.142)
L.Ln(Exports)	-0.035**
	(0.015)
L.Catch share	-0.199
	(0.407)
Long-run effect	-0.082***
Instrument #	45
AR(1) p-value	0.001
AR(2) p-value	0.786
Hansen p-value	0.208
Observations	9362

Standard errors (clustered at the country-species level) in parentheses. Standard errors for the long term effect are calculated using the delta method.
* $p<0.1$, ** $p<0.05$, *** $p<0.01$

coefficient estimate for the export quantity in Table 6. The results suggest that an increase in exports by one percent reduces stock biomass by 0.04 percent in the following period. In the long-term, an increase in exports by one percent is estimated to reduce stock biomass by 0.08 percent (see lower half of Table 6). This corroborates the finding that exporting has a negative effect on fish stocks.

7 Sensitivity analysis

This section shows that the results are not driven by potential violations of the exclusion restrictions. It investigates whether the collapse of a Japanese fishery and the fishery in the exporting country are potentially related to each other via (a) landings of the Japanese foreign fishing fleet (b) Japanese exports which lead to a collapse in the Japanese fishery or (c) unobserved environmental factors. There is no evidence that any of these channels are at work.

Further robustness tests are available in the Appendix. Section 10.1 investigates the robustness of the results to changes in the instrumental variable. The fisheries collapse in Japan is interacted with the exporting country's distance from Japan to reflect the empirical regularity that trade flows are higher between close neighbours. Section 10.2 dispels concerns about a potential downward bias in the coefficient estimates resulting from substitution effects. Section 10.3 shows that the results are not biased due to measurement error in the dependent variable. Alternative sets of fixed effects are presented in Section 10.4. The findings follow through if net exports are used as an alternative measure for trade openness (Section 10.5). Species that are suitable for aquaculture production dot not seem to be depleted due to exports, as demonstrated in Section 10.6.

7.1 The Japanese foreign fishing fleet's catch does not increase

The empirical strategy assumes that the collapse of Japanese fisheries only affects a collapse in other countries due to exports. In principle, it is also possible that the Japanese foreign fishing fleet increases its catch in other countries' Exclusive Economic Zones as a result of the Japanese collapse. This would violate the exclusion restrictions since the Japanese foreign fishing fleet's activity could raise the probability of a collapse in the exporting countries in the sample.

In practice, this is not a concern. First, increasing costs lead to the decline of the Japanese long distance fleet (Swartz et al., 2010). Currently, the Japanese long distance fleet's activity focuses on tuna or takes place in the EEZs of China, South Korea and Russia. Since neither tuna nor Japan's neighbours are included in the sample, the Japanese fleet's activities do not invalidate the instrument. Second, there is no evidence that Japanese fishing in distant waters increases as a result of a collapse in Japan, as shown in Table 11 in the Appendix.

Third, the results do not change once landings by the Japanese foreign fishing fleet off the exporting country's waters are controlled for. The control variable "Jap. landings$_{ikt}$" measures Japanese catch (in tonnes) of species i in year t in FAO fishing areas adjacent to country k's borders.[30] Controlling for "Jap. landings$_{ikt}$" yields a coefficient estimate of 0.114 for exports. This is almost identical to the coefficient estimate in the baseline regression.

[30]The FAO divides the world's oceans into 19 marine fishing areas. A map of the marine fishing areas is available on http://www.fao.org/fishery/area/search/en. Data on Japanese landings in each FAO fishing area are from the FAO's global capture production database.

Table 7: No violation of instrument exogeneity

	(1) Long distance	(2) Exports	(3) Northeast	(4) West. C	(5) Lagged IV
Exports	0.114**	0.122**	0.112***	0.116**	0.131**
	(0.046)	(0.061)	(0.037)	(0.047)	(0.053)
L.Jap landings	-0.001***				
	(0.000)				
IV	L.Col. Jap.	L.Col. Jap.	L.Col. Jap.	L.Col. Jap.	L2.Col. Jap.
1st stage F-Stat	10.729	11.531	16.025	11.111	9.273
Anderson-R. p-value	0.003	0.011	0.002	0.004	0.000
No. of clusters	108	105	93	106	105
Observations	8880	8388	8134	8357	8716

Dependent variable: Collapsed. The sample excludes all country-species-combinations from the sample in which the first reported collapse of fishery i in the exporting country k precedes the first reported collapse of fish species i in Japan in Column 2, the US and Canada in Column 3, countries in the Western Pacific in Column 4. Standard errors (clustered at the species level) in parentheses. The p-value of the Anderson and Rubin (1949) test (Anderson-R. p-value) provides weak instrument robust inference.

* p<0.1, ** p<0.05, *** p<0.01

7.2 A collapse in Japan is not driven by Japanese exports

The exclusion restrictions would also be violated if a species' collapse in Japan was the result of the same species' collapse in the exporting country. This is unlikely to drive the results for several reasons. First, fisheries are only observed in the dataset up to the year in which they collapse. Therefore, the estimates are not affected by events that happen as a result of a collapse in the exporting country unless the fishery recovers and reappears in the dataset. Second, Figure 2 shows that Japan exports a small fraction of its landings and is a net importer throughout the sample period. Hence, it is unlikely that exports caused the collapse of Japanese fisheries.

Third, it is reasonable to think of Japan as the first (or at least an early link) in a potential chain of serial resource collapse. In the entire sample of Sea Around Us catch data (not all of which are used in the analysis due to a lack of export data), 113 fish species collapsed in Japan prior to 2006. For 30 percent of those species, Japan was the first country worldwide to report a collapse of the respective species.

The baseline results follow through in a sample that excludes all country-species-combinations in which the first reported collapse of fish species i in the exporting country k precedes the first reported collapse of fish species i in Japan (see Column 2 of Table 7).

7.3 Environmental factors do not violate instrument exogeneity

This section shows that the exclusion restrictions are not violated due to ecosystem linkages and shared environmental shocks. In the baseline model, region-year-fixed effects capture all biological and climatic shocks affecting all species in the same way in one region. Moreover, Japan's direct neighbours, which would be affected by similar environmental factors, are excluded from the sample.

To further reduce the probability of ecosystem spillovers and shared environmental shocks, the US and Canada are excluded from the sample. The coefficient estimate of 0.116 in Column 3 of Table 7 is very similar to the baseline result and indicates that the findings in this paper are not driven by common shocks between Japan and the US or Canada. Moreover, there is no evidence of biased coefficient estimates due to common shocks affecting Japan and countries in the Western Pacific. Column 4 of Table 7 shows that the results follow through in a sample that excludes countries in the Western Pacific (FAO fishing area 71).

The probability of ecosystem linkages and shared shocks between Japan and the exporting country can be reduced further using the collapse in Japan in year *t-2* as an instrumental variable. This yields a marginally higher coefficient estimate of 0.13 than the baseline regression (see Column 5 of Table 7).

8 Conclusion

This paper investigates the causal effect of fisheries exports on the collapse of fisheries. The analysis is based on a newly-constructed, global panel dataset with variation at the country-species-year level. Due to the endogeneity of exports, the collapse of Japanese fisheries is used as an instrument for exports of fishery products.

Exports have a large negative impact on fisheries' viabilities. An increase in logged exports by one standard deviation raises the probability of a collapse in the following year by 29 percentage points. The estimated effect is large but not unrealistic. The predicted increase in the probability of collapse for a fishery with median export growth is equivalent to roughly two thirds of the observed increase in the proportion of collapsed fisheries over a 15 year time window.

The results highlight the importance of fisheries management. Exporting only causes a collapse of fisheries that are not regulated via ITQs or other catch share programs. This suggests that trade liberalization should be accompanied by the implementation of fisheries management in exporting countries.

The introduction of sustainable management is particularly important for developing countries, which export half of the global export value (FAO, 2016*b*). In those countries, exports of fishery products are an important source of foreign exchange earnings, income and employment. However, the use of catch share programs is not very wide-spread in the developing world (Jardine and Sanchirico, 2012). In order to guarantee long-term benefits from fisheries exports, developing countries should consider the introduction of catch share programs or similar management tools.

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9 Theoretical Appendix

9.1 Demand for fish

A representative consumer has Cobb-Douglas preferences for individual consumption of a manufactured product m and fish h. The taste parameter β $(0 < \beta < 1)$ reflects the consumer's taste for fish and the utility function is given by

$$u = h^{\beta} m^{(1-\beta)}. \tag{8}$$

In every time period, the representative consumer maximizes consumption subject to a budget constraint

$$ph + m = w \tag{9}$$

where w is the worker's wage income. The price of the manufactured product is normalized to 1 and p is the price of fish. Maximizing utility (8) subject to the budget constraint (9) yields the individual demand for fish $h = \beta w/p$ and manufactured goods $m = (1-\beta)w$. Multiplying individual demand by the number of workers in the economy L_T yields the aggregate demand for fishery products

$$H^C = hL_T = \frac{\beta w L_T}{p}. \tag{10}$$

9.2 Price of fish

The fishery is assumed to be unregulated. Open access to the fishery results in zero profits such that the revenue from fishing equals the fishing cost $pH = wL_H$. Solving for H and substituting this into the catch function in Equation 3 yields

$$\frac{w}{p} L_H = \alpha L_H S^{\tau}. \tag{11}$$

This equation can be solved for the open access resource price

$$p = \frac{w}{\alpha S^{\tau}}. \tag{12}$$

In a diversified economy, $w = 1$. This yields the resource price depicted in the bottom panel of Figure 1.

9.3 Short run equilibrium harvest

Substituting the short run price from Equation 12 into the aggregate demand for fish from Equation 10 allows us to pin down the short run supply of fish as a function of the stock size

$$H = \beta L_T \alpha S^{\tau}. \tag{13}$$

9.4 Diversified steady state with a smaller stock

One potential outcome of international trade is a diversified steady state with a smaller resource stock. A diversified steady state occurs if the stock declines to a point at which the marginal value product of workers in both industries equalizes. This is the case if a reduction in the stock reduces fishing productivity such that $p^* \alpha S_T^{\tau} = 1$. Solving this Equation for S_T allows us to show that exporting leads to an unambiguous reduction in the resource stock compared to the autarky stock

$$\frac{S_T}{S_A} = \left(\frac{\frac{1}{p^* \alpha}}{\frac{1}{p_A \alpha}} \right)^{\frac{1}{\tau}} = \left(\frac{p_A}{p^*} \right)^{\frac{1}{\tau}} < 1. \tag{14}$$

The steady state stock under trade is smaller than the autarky stock ($S_T < S_A$) if $p^*/p_A > 1$. Equation 14 also shows that exporting is more detrimental to schooling fish species for which τ is small.

9.5 Specialized steady state

A specialized steady state is possible at high world market prices, when the specialized catch function and the resource growth function intersect. Let us define S_z as the stable steady state stock at which the specialized catch function equals resource growth and $p_z = 1/(\alpha S_z^{\tau})$. If the economy opens up to trade and the world market price is given by $p^* > p_z > p_A$, the economy instantly specializes in fishing and catch surges. The stock shrinks gradually due to the intense fishing pressure. Once the stock has diminished to S_z, it cannot decline further. If the stock were to decline slightly more, resource growth would exceed catch and the stock would recover. Therefore, S_z is a stable steady state and the fishery cannot collapse even at high resource prices. The economy remains specialized at S_z, since the marginal value product of labour in fishing exceeds the marginal value product of manufacturing at $p^* > p_z$.

9.6 Conditions for a collapse to be possible

A fishery collapses if (1) $p_c \geq 1/(\alpha \underline{\mathrm{S}}^{\tau})$ and if (2) catch under specialization exceeds resource growth for any stock $S > 0$. Condition (1) is more likely to be satisfied if fishing technology is advanced (α is high), if the minimum viable stock size $\underline{\mathrm{S}}$ is high and if fish species form schools implying that τ is low. Condition (2) requires that

$$L_T \alpha S^{\tau} > r\left[S - \underline{S}\right]\left[1 - \frac{S}{K}\right]. \tag{15}$$

Manipulating terms yields

$$S^2 + (L_T \alpha K/r) S^{\tau} - KS + \underline{S}(K - S) > 0 \tag{16}$$

Condition (2) is more likely to hold if fishing pressure is high relative to resource growth, i.e. $L_T \alpha / r$ is high. Since the stock cannot exceed carrying capacity, $K - S$ must be strictly positive. Therefore, this condition is also more likely to be satisfied when the minimum viable stock size $\underline{\mathrm{S}}$ increases. An increase in the carrying capacity K makes it more likely that this condition holds as long as $(L_T \alpha / r) S^{\tau} - S + \underline{S} > 0$. For any stock $S > 1$ this condition is also more likely to be satisfied if τ is large.

10 Empirical Appendix

Table 8: Fisheries collapse by taxa

	Collapse in Observations	Collapse in exporting countries	Japan
Abalones, winkles, conchs	62	3	2
Clams, cockles, arkshells	2	0	0
Cods, hakes, haddocks	2174	109	32
Crabs, sea-spiders	133	1	3
Flounders, halibuts, soles	1606	52	23
Herrings, sardines, anchovies	1031	59	5
King crabs, squat-lobsters	92	11	0
Lobsters, spiny-rock lobsters	572	20	0
Miscellaneous coastal fishes	255	4	18
Miscellaneous demersal fishes	581	38	30
Miscellaneous pelagic fishes	532	21	18
Oysters	65	6	0
Salmons, trouts, smelts	401	35	5
Scallops and other pectens	141	8	0
Sea-urchins and other echinoderms	207	4	0
Shads	25	0	0
Sharks, rays, chimaeras	95	1	9
Shrimps, prawns	181	13	0
Squids, cuttlefishes, octopuses	725	28	15

This table shows the number of observations (Column 1) as well as the number of collapsing fisheries for exporting countries (Column 2) and Japan (Column 3) by species category.

Table 9: Catch as regressor

	(1) Collapse
Catch (lag, ln)	0.230
	(0.142)
Fixed effects: γ_{rt}, γ_i, γ_k and controls	Yes
1st stage F-Stat	2.099
Anderson-R. p-value	0.004
Observations	8870

Standard errors (clustered at the species level) in parentheses. The p-value of the Anderson and Rubin (1949) test (Anderson-R. p-value) provides weak instrument robust inference.

* p<0.1, ** p<0.05, *** p<0.01

Table 10: Catch share adoption is exogenous

	(1) Catch share program$_t$
Collapsed$_{ikt-1}$	-0.0009
	(0.0058)
Country-species FE, Year FE	Yes
Observations	7950

This table shows the relationship between the collapse of a fishery in year $t-1$ and the government's decision to introduce a catch share program in year t. In the dataset used for this analysis, a fishery is observed up to the year in which it introduces a catch share program. Fisheries that do not introduce catch share programs are observed until the end of the sample period. Standard errors (clustered at the country-species level) in parentheses.

* p<0.1, ** p<0.05, *** p<0.01

Table 11: Long distance fleet landings do not increase

	(1) Long distance total catch
Col. Japan	-781.931
	(1075.277)
Observations	1318

Long distance total catch$_{it}$ is regressed on the collapse of species i in Japan in year t, on year fixed effects and species fixed effects. Long distance total catch$_{it}$ is measured in tonnes and represents Japanese catch of species i in year t in all FAO fishing areas except the fishing area surrounding Japan. The sample does not include highly migratory and high seas fish stocks. Standard errors (clustered at the species level) in parentheses.

* p<0.1, ** p<0.05, *** p<0.01

10.1 Exporter's distance from Japan

The results from the baseline regression follow through if the collapse of a Japanese fishery is interacted with the country's distance from Japan.

Exports are likely to react less to the collapse of a Japanese fishery the further the country is from Japan.[31] Therefore, the instrumental variable "Collapse Japan" is interacted with a measure for the distance between Japan and the exporting country. Distance is measured as the great circle distance (in 1000km) between the cities with the largest population in each country using data from the CEPII GeoDist database (Mayer and Zignago, 2011).

With this instrument, an increase in exports by one percent is estimated to raise the probability of a collapse by 0.12 percentage points. This coefficient estimate, which is displayed in Column 2 of Table 12, is only slightly higher than the coefficient estimate in the baseline regression.

10.2 No evidence of substitution effects

Substitution effects may occur since the collapse of a Japanese fishery is associated with an increase in the price of the collapsed species. In response to this increase in price, consumers may shift their expenditure to a close substitute. This, in turn, could raise the price of, and export demand for, the substitute, and induce fishermen to harvest more of the substitute. The resulting increase in the probability of a collapse of the substitute would contaminate the control group and bias the coefficient estimates downward. In case of substitution effects, the coefficient estimate for the export quantity in the baseline regression would have to be interpreted as a lower bound. This section argues that there is no evidence of a downward bias resulting from substitution, neither on the demand side nor on the supply side.

10.2.1 No evidence of substitution on the demand side

This section highlights that a collapse of a species in Japan does not raise export demand for a substitute. Species from the same Family are likely to be close substitutes since they share a lot of characteristics. Therefore, the variable "Col. J.

[31] It is a well-established empirical fact that trade flows are negatively correlated with distance (see e.g. Head and Mayer, 2014).

Table 12: Alternative instruments and substitution effects

	(1) IV distance	(2) Substitution 1	(3) Substitution 2
Export quantity (lag, ln)	0.123**	0.109**	0.133**
	(0.062)	(0.046)	(0.052)
Percentage collapsed			0.504***
			(0.120)
FEs and controls	Yes	Yes	Yes
IV 1	Col. Japan*distance	L.Col. Japan	L.Col. Japan
IV 2	-	L.Col. J. Family	-
1st stage F-Stat.	5.828	5.214	9.673
Anderson-R. p-value	0.008	0.013	0.001
No. of clusters	108	108	108
Observations	8876	8880	8880

Standard errors (clustered at the species level) in parentheses
* p<0.1, ** p<0.05, *** p<0.01

Family$_{it}$" can be used as a second instrument to assess spillover effects. The variable takes a value of 1 if a species is in the same Family as the collapsed Japanese species i in year t. A positive and statistically significant coefficient estimate for the variable "Col. J. Family$_{it}$" in the first stage regression would indicate that export demand for species in the same Family increases when the species collapses in Japan.

There is no evidence of substitution effects amongst similar fish species. In the first stage regression, the coefficient estimate for "Col. J. Family$_{it}$" is not significant. Moreover, the results in the second stage regression are not affected by the introduction of this second instrument. Column 2 of Table 12 shows that an increase in exports by one percent is estimated to raise the probability of a fishery's collapse by 0.11 percentage points. This is very similar to the findings in the baseline regression. It is reassuring that the test for overidentifying restrictions suggests that the instruments are valid.

10.2.2 Substitution on the supply side does not drive results

Moroever, there is little concern of a downward bias in the coefficient estimates resulting from substitution on the supply side. If there is substitution on the supply side, fishermen will catch more of species j in the years following a collapse of species i.

This kind of substitution on the supply side is likely to be limited by the fact that the different fish species in the sample are caught in different parts of the sea using a broad range of fishing gear and different fishing technology. Therefore, fishermen potentially have to invest in alternative fishing gear in order to target a different species. The immediate increase in fishing pressure for species j as a result of a collapse of species i is therefore likely to be low.

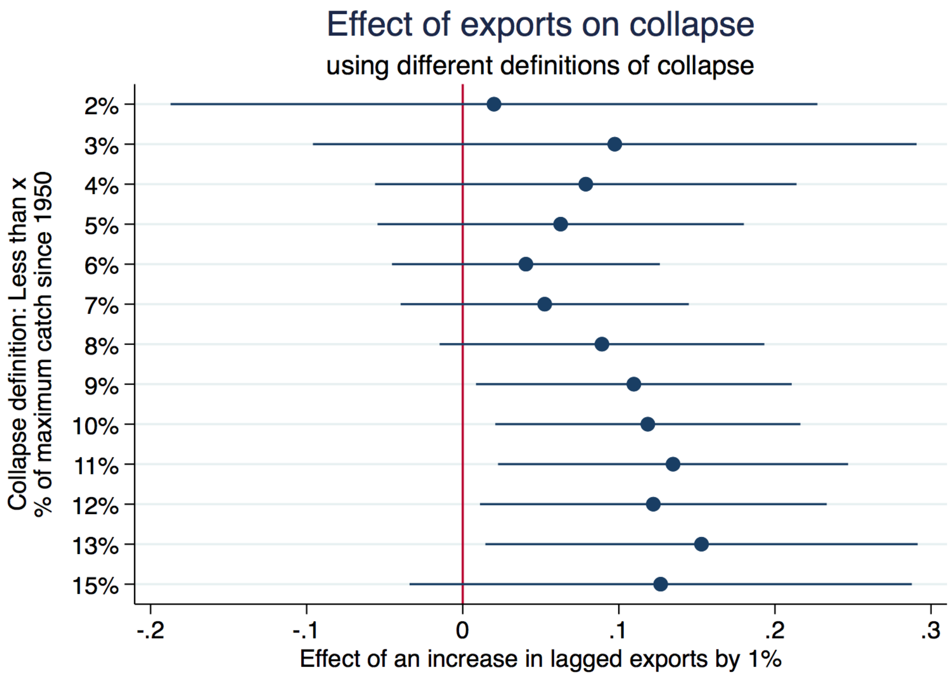
Moreover, the results follow through if the analysis accounts for different trends in the probability of a collapse resulting from substitution on the supply side. If fishermen target species j in response to a collapse of another species, fishing pressure for species j and the probability of a collapse of fishery jkt should increase in the proportion of collapsed fisheries within country k at time t. Controlling for the proportion of collapsed fisheries captures different trends and removes any bias resulting from substitution on the supply side. Column 3 of Table 12 shows that an increase in exports raises the probability of a collapse by 0.13 percentage points. The effect is only slightly higher than the coefficient estimate in the baseline regression.

10.3 Measurement error in fisheries collapse

Even though the collapse of fisheries is inferred based on catch statistics, measurement error in the dependent variable does not seem to bias the results. The results are (mostly) robust to changes in the definition of fisheries collapse.

It is possible that a fishery is falsely measured as collapsed when a government introduces particularly strict catch limits. Those catch limits could lead to a drastic reduction in catch that does not represent a collapse of the fish stock. This would only bias the results if the resulting measurement error in fisheries collapse was systematically related to the instrumental variable. However, there is no reason to believe that the introduction of strict catch limits outside of Japan is related to the collapse of the same species in Japan. Moreover, measurement error resulting from fisheries collapse does not appear relevant in the study sample. There are only three fisheries in the sample for which the introduction of catch share programs coincides with the collapse of the fishery. Stock data, which are available for one of those fisheries, suggest that the stock had actually declined drastically. The results are very similar to those from the baseline regression, if the above-mentioned three fisheries are excluded from the sample.

Figure 8: Effect of exports on collapse using different definitions of collapse



The figure displays the estimated effect of a one percent increase in lagged exports as well as the 95% confidence intervals for separate regressions, each using a different definition of fisheries collapse. A fishery is defined as collapsed if catch is less than x percent of the maximum catch recorded since 1950.

The results are also (partly) robust to changing the definition of fisheries collapse. This is shown by Figure 8 which defines collapse as having occurred with different percentages of the maximum catch since 1950. The figure displays the estimated effect of a one percent increase in lagged exports on the probability of a collapse for separate regressions each using a different definition of fisheries collapse. A fishery is defined as collapsed if catch is less than x percent of the maximum catch recorded since 1950, where all cut-offs, x, between 2% and 15% are considered. The coefficient estimates are presented with 95% confidence intervals.

The results point towards a statistically significant increase (at the 10%) level in the probability of a collapse, as long as the cut-off is between 8% and 14%. The coefficient estimates are statistically significant using weak-instrument robust inference for cut-offs of 4%, 15% and 16%. For all other cut-offs, the coefficient estimates are positive but not significant. However, particularly for small cut-offs, the coefficient estimates may be biased downwards since the instrument is weak.[32]

10.4 Different fixed effects

The results follow through with different sets of fixed effects, as shown in Table 13. Column 1 shows results with year fixed effects, country fixed effects and species fixed effects. Column 2 presents results with region time trends, species fixed effect and country fixed effects and Column 3 shows results with species fixed effects and country-year fixed effects. Finally, Column 4 represents results with year fixed effects and country-species fixed effects. The coefficient estimates are larger than in the baseline regression and all of them are statistically significant using weak instrument robust inference. In anything, the baseline regression underestimated the true effect size.

10.5 Different measures for exports

It is possible that a country both exports and imports the same species. This section investigates whether we come to similar conclusions using net exports, defined as exports minus imports at the country-species-year level, as a regressor.

The estimated effect of net exports on fisheries collapse is stronger than the effect of gross exports. The results in Column 1 of Table 14 suggest that an increase in net exports by one percent raises the probability of collapse in the following period by 0.22 percentage points. This is almost twice the effect size found in the baseline regression.

The long-term effect of net exports on the collapse of a fishery can be captured by the maximum of a fishery's previous net exports. Column 2 of Table 14 shows that an increase in maximum historical net exports by one percent raises the probability of a fishery's collapse by 0.10 percentage points. These findings indicate

[32] Even though the definition of fisheries collapse depends on an arbitrary cut-off, the use of catch relative to maximum historical catch would not be a better dependent variable. The theoretical model in Section 2 shows why this is the case. The variable "Collapse" is a proxy for a very small or depleted fish stock and Hypothesis 1 clearly predicts that an exogenous increase in the price in period $t-1$ is associated with a smaller stock period t. Therefore, the collapse in Japan raises the probability of a collapse in the exporting country. However, it is not generally the case that an exogenous increase in the price in period $t-1$ leads to a smaller catch in period t. A country which is in a diversified steady state in period $t-2$ and specializes in fisheries in period $t-1$ does not necessarily catch less in period t than in period $t-2$ if it remains specialized in period t.

Table 13: Different fixed effects

	(1)	(2)	(3)	(4)
L.Exports	0.134**	0.149**	0.150	0.171
	(0.056)	(0.064)	(0.093)	(0.156)
Year FE	✓			✓
Region time trend		✓		
Species FE	✓	✓	✓	
Country FE	✓	✓		
Country-year FE			✓	
Country-species FE				✓
Controls	✓	✓	✓	✓
1st stage F-Stat	9.427	7.953	3.948	2.193
Anderson-R. p-value	0.003	0.001	0.052	0.047
No. of clusters	108	108	108	106
Observations	8880	8880	8884	8819

Standard errors (clustered at the species level) in parentheses. The p-value of the Anderson and Rubin (1949) test (Anderson-R. p-value) provides weak instrument robust inference.

* p<0.1, ** p<0.05, *** p<0.01

that net exports have a significant and large negative impact on the sustainability of fisheries both in the short- and long-term.

10.6 Aquaculture

The possibility to harvest a species using aquaculture production seems to take pressure off wild-capture fisheries and dampen the effect of exports on the collapse of fisheries. There is tentative evidence that species that are suitable for aquaculture production are not depleted due to exports (see Column 3 of Table 14). Column 4 of Table 14 reveals that the results from the baseline regression follow through if fisheries which report positive aquaculture production are excluded from the sample.

Table 14: Net exports

	(1)	(2)	(3)	(4)
Dependent variable:	Collapsed	Collapsed	Collapsed	Collapsed
Sample:	All	All	Aquaculture	No aquaculture
L.Ln(Net Exports)	0.222			
	(0.227)			
Ln(Max. Net Exp.)		0.102*		
		(0.054)		
L.Exports			-0.087	0.115**
			(0.218)	(0.046)
Fixed effects and controls	Yes	Yes	Yes	Yes
1st stage F-Stat	1.208	5.377	1.613	10.303
Anderson-R. p-value	0.010	0.017	0.622	0.004
No. of clusters	105	109	13	107
Observations	5801	9087	334	8544

Standard errors (clustered at the species level) in parentheses. The p-value of the Anderson and Rubin (1949) test (Anderson-R. p-value) provides weak instrument robust inference.

* p<0.1, ** p<0.05, *** p<0.01