

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

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Do exports of renewable resources lead to resource depletion? In the case of fisheries, the answer is yes. This paper uses country-species-level fisheries data to estimate the causal effect of exporting on the collapse of fisheries. The collapse of Japanese fisheries is used as an instrument for fisheries exports in countries which do not share fish stocks with Japan. Since Japan is a large market for fishery products, the Japanese collapse spurs export demand in other countries. The results reveal that exports significantly contribute to fisheries depletion. An increase in logged exports by one standard deviation raises the likelihood of a fishery's collapse in the following period by 23 percentage points. Fisheries which are not managed via quotas are more severely affected.

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1 Introduction

A large proportion of the world's fisheries are overfished and the collapse of fish stocks is becoming ever more prevalent. In 2003, 27% of the world's fisheries had collapsed ([Worm et al., 2006](#)). At the same time, 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](#)). Is this a coincidence or do exports cause fisheries depletion?

This paper uses rich country-species-year level fisheries data to estimate the causal effect of fisheries exports on the likelihood of a fishery's collapse. I employ a novel identification strategy, using an export demand shock originating from Japan as an instrument for exports in other countries. This allow me to address the omitted variable bias which results from the fact that both exports and the probability of a collapse depend on the size of the fish stock, which is unobserved. The results suggest that an increase in exports leads to a large increase in the likelihood of a collapse, particularly in fisheries which are not regulated via quotas or other rights-based fisheries management tools.

Insights on the effect of exports on fisheries depletion are particularly relevant for developing countries, where fisheries generate a significant proportion of export revenue ([Bellmann et al., 2016](#)) as well employment and food for millions of people. Yet, these benefits are short-lived if fisheries collapse as a result of exports.

From a theoretical point of view, it is well understood that exporting can lead to overfishing in open access fisheries ([Brander and Taylor, 1997a,b, 1998](#); [Chichilnisky, 1994](#); [Hannesson, 2000](#)). However, only [Copeland and Taylor \(2006\)](#) discuss the possibility of a resource collapse as a result of trade. To set the scene for the empirical estimation, I extend the model by [Brander and Taylor \(1997a\)](#) and show that exporting can lead to the collapse of fish stocks which would not collapse in autarky. I focus on a situation in which a trade liberalization is associated with an exogenous increase in the price of fish. This increase in the price makes fishing more lucrative and, as a result, the country catches more fish and exports fishery products. Since catch exceeds fish population growth, the fish stock shrinks over time. At high world market prices, exporting can lead to the collapse of the fishery. However, a collapse only occurs if fishing 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. I use a standard definition of fisheries collapse (see e.g. [Worm et al., 2006](#); [Costello et al., 2008](#)) and define 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 only available for a very small number of fish stocks globally.

The collapse of Japanese fisheries is used as an instrument for exports of fishery products in order to make causal inference. Since Japan is one of the largest markets for seafood products, the collapse of a Japanese fishery raises the world market price of the affected species and spur exports in other countries. Therefore, the collapse of a Japanese fishery is positively correlated with exports in other countries.

The empirical strategy takes two steps to ensure that trade is the only channel via which a collapse in Japan can affect a collapse in the exporting country. Firstly, the sample does not include fisheries which 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. Secondly, I control for other economic, biological and climatic factors which could lead to the collapse of a fish species in both countries.

I construct a comprehensive country-species level panel dataset which allows me to get both detailed and broadly applicable insights on the effect of exports on resource depletion. Insights are detailed since I link 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 many of the case studies in the literature on trade in renewable resources.

I find that exports significantly contribute to overfishing. The results suggest that an increase in exports by one percent raises the likelihood 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 144 percent between 1976 and 2006. According to the estimates, this export boom raised the likelihood of a collapse by around 12.5 percentage points. This predicted effect is equivalent to more than two thirds of the observed increase in the percentage of collapsed fisheries.

Fisheries which are not regulated via fishing quotas or similar rights-based management approaches are more severely affected by exports. This is in line with

theoretical predictions that exports only harm open access fisheries ([Brander and Taylor, 1997a,b, 1998](#); [Chichilnisky, 1994](#); [Hannesson, 2000](#)). Moreover, this result highlights that adequate regulation of fisheries is necessary to guarantee long term benefits from fisheries for exporting countries.

This paper is structured as follows. Section 2 reviews the relevant literature. The theoretical background for the analysis is presented in Section 3. Section 4 presents the empirical strategy. It discusses the potential bias in the OLS regression, explains the choice of the instrument as well as the estimating equation. The results from a benchmark OLS regression and an instrumental variable regression are presented in Section 6, followed by a sensitivity analysis in Section 7. Section 8 concludes.

2 What do we know about trade and resource depletion?

The theoretical literature on trade in renewable resources suggests that exporting exacerbates the overexploitation of open access renewable resources ([Brander and Taylor, 1997a,b, 1998](#); [Chichilnisky, 1994](#); [Hannesson, 2000](#)). There is little empirical work to support this prediction. The lack of species level information on trade flows and the need to address reverse causality between resource exports and resource stocks have been the two main limiting factors. This paper addresses both of these challenges. It is the first paper to estimate the causal effect of fisheries exports on fisheries depletion.

The sparse empirical literature on trade in renewable resources suggests that exporting may lead to the overharvesting of renewable resources, particularly if they are unregulated. [Barbier et al. \(1990\)](#), e.g., show that ivory trade lead to the slaughtering of elephants due to poor enforcement of property rights for elephants. Trade also lead to the near extinction of the North American Bison in the absence of property rights ([Taylor, 2011](#)). [Ferreira \(2004\)](#) finds that trade accelerates deforestation in countries with poor institutional quality. There is further evidence that trade increased deforestation in Ghana ([López, 1997](#)) and in Brazil ([Faria and Almeida, 2016](#)).¹ These findings are in line with this paper's result that exporting only leads to the collapse of fisheries which are not regulated via catch share

¹The list of papers mentioned here is not exclusive. Please see [Bulte and Barbier \(2005\)](#), [Fischer \(2009\)](#) and [Copeland \(2011\)](#) for more comprehensive reviews of the literature on trade in renewable resources.

programs.

This paper improves on the existing empirical literature in three ways. Firstly, I estimate the causal effect of exports on the depletion of a renewable resource and address reverse causality between exports and resource stocks. Amongst the above-mentioned studies, only [Taylor \(2011\)](#) provides convincing evidence of a causal effect of exports on the extinction of buffalos in North America.

Secondly, this paper provides better estimates of the effect of resource exports on resource depletion since it uses species level data on export quantities as well as data on trade barriers for fishery products in major seafood markets. Few of the above-mentioned papers use data on trade flows or trade barriers. [Ferreira \(2004\)](#) and [Faria and Almeida \(2016\)](#), for example, use export+imports relative to GDP at the country level as proxies for trade openness. This does not reflect trade flows in the resource under investigation. [Taylor \(2011\)](#) uses information on trade flows but he has to rely on estimates of exports.

Finally, this paper analyses the effect of fisheries exports on the depletion of fisheries, whereas most of the existing literature focuses on ivory trade or trade in forest products. To the best of my knowledge, the working paper by [Erhardt and Weder \(2015\)](#) provides the only empirical analysis of the relationship between trade and overfishing. They find tentative evidence that shark species which are traded internationally are at a higher risk of extinction according to the IUCN Red List of Threatened Species. [Erhardt and Weder \(2015\)](#)'s analysis has several shortcomings which this paper remedies. Firstly, [Erhardt and Weder \(2015\)](#) only provide conditional correlations whereas this paper establishes a causal link between trade and fisheries collapse. Secondly, [Erhardt and Weder \(2015\)](#) proxy trade via a dummy variable which takes the value of one if there are reports that a particular shark species is traded internationally. They do not use data on trade flows and cannot distinguish between the effect of trade on shark populations in exporting and importing countries. The use of country-species specific panel data on trade flows allows me to quantify the extent to which trade leads to the collapse of fisheries in exporting countries. Thirdly, [Erhardt and Weder \(2015\)](#)'s analysis is restricted to shark species whereas this paper uses data on more than 100 different species. This allows me to generalize [Erhardt and Weder \(2015\)](#)'s result.

The analysis in this paper also provides evidence for one link in a potential chain of serial fisheries collapse, since the reduced form regression suggests that the collapse of a Japanese fishery raises the likelihood of a collapse in other exporting countries.

The theoretical model by [Copeland and Taylor \(2006\)](#) shows that Ricardian trade between a large number of countries can lead to serial depletion of fisheries. Several papers provide anecdotal evidence of a serial decline of fisheries. Examples are the serial depletion of crab and shrimp fisheries in the Gulf of Alaska ([Orensanz et al., 1998](#)), the depletion of oysters along the east and west coast of North America and eastern Australia ([Kirby, 2004](#)). However, none of these paper investigate the role of trade in serial fisheries depletion.

[Anderson et al. \(2011\)](#) and [Berkes et al. \(2006\)](#) describe empirical results which are *consistent with* serial depletion due to trade. [Anderson et al. \(2011\)](#) argue that the serial depletion of sea cucumbers were driven by exports to the Chinese market and [Berkes et al. \(2006\)](#) holds that the "[c]ommercial sea urchin harvest began largely for export to Japanese markets, after Japan's own resources declined" ([Berkes et al., 2006](#), p. 1557). The papers are excellent examples of the mechanism described in this paper. I argue that a collapse of a fish species in a major seafood market like Japan fosters exports of the same species in other countries. This, in turn, leads to the collapse of fisheries in the exporting countries. However, this is the first paper to use data on trade flows in order to quantify the extent to which exports contribute to serial fisheries depletion. Moreover, it generalizes the patterns described in [Berkes et al. \(2006\)](#) and [Anderson et al. \(2011\)](#) to a large number of species.

3 Theoretical background: Exporting can lead to the collapse of fisheries

This section provides the theoretical background for the empirical analysis and shows how exporting affects fish stocks. 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. Fisheries which are sustainable in autarky can collapse at high world market prices.

The model presented in this section is a Ricardian trade model. It closely follows [Brander and Taylor \(1997a\)](#). However, the resource growth function is extended in the same way as in [Copeland and Taylor \(2006\)](#) to show that exporting can lead to the collapse of the fishery. This section provides an intuitive explanation of the way

trade affects the fishery. Technical details are deferred to Section 9 in the Appendix.

3.1 Supply side

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

3.1.1 Fishing

Prior a description of the fishing industry, I explain 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 fishing $H(t)$, such that

$$dS/dt = G(S(t)) - H(t). \quad (1)$$

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 \(1997a\)](#) is extended by a minimum viable stock size \underline{S} to obtain

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

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. For any stock $S > \underline{S}$, the resource grows at a positive rate until it has reached its carrying capacity K , at which point the natural environment does not support any additions to the stock.

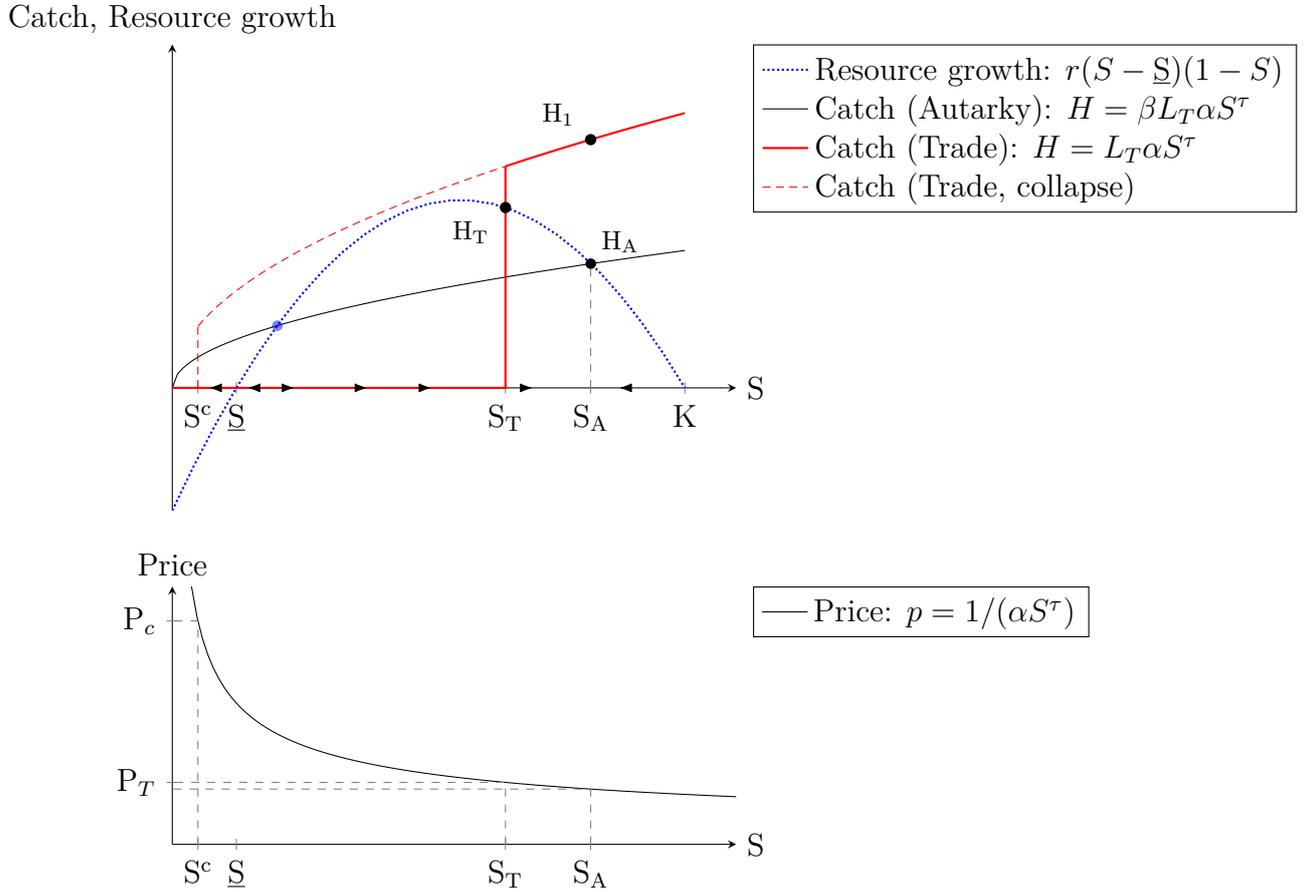
Fishing is characterized by the following function in which α describes the fishing technology and τ is a schooling parameter²

$$H = \alpha S^\tau L_H. \quad (3)$$

The term αS^τ in this equation captures fishing productivity. Each worker in the

²This catch function is also used by [Copeland and Taylor \(2006\)](#). The schooling parameter is an extension of the model by [Brander and Taylor \(1997a\)](#).

Figure 1: Resource dynamics and catch function



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 . Schooling fish species are relatively easy to catch when the stock is small. When a species form 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, it is possible to solve for the price of fish, p , as a function of the stock size (see 9.2 in the Appendix)

$$p = \frac{w}{\alpha S^\tau}. \quad (4)$$

Equation 4 reflects the country's productivity in fishing in the short run, when the

stock can be considered fixed. A better fishing technology α and a bigger stock S are associated with a lower price.

3.1.2 Manufacturing

Manufacturing production technology is given by

$$M = L_M. \quad (5)$$

The price of the manufacturing product is normalized to 1. Therefore, the wage rate in manufacturing equals its marginal value product and $w = 1$. Labour is assumed to be mobile across industries and hence the wage rate in fishing must also equal 1 in a diversified economy.

3.2 Demand side

On the demand side, all workers are assumed to have Cobb-Douglas preferences. With those preferences, workers always consume both products and spend a constant fraction β of their income on fish. Section 9.1 in the Appendix shows that aggregate demand for fish, H^C , is

$$H^C = \frac{\beta w L_T}{p}. \quad (6)$$

3.3 Short run autarky equilibrium

Substituting the short run price from Equation 4 into the aggregate demand for fish from Equation 6 pins down the short run supply of fish as a function of a given stock size

$$H = \alpha S^\tau \beta L_T. \quad (7)$$

Equation 7 represents the "short-run catch function". It is depicted by the black line in Figure 1. Equation 7 shows that, in the short-run equilibrium, a fraction β of workers is employed in fishing.

3.4 Autarky steady state

In the 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.³ Figure 1 shows that the catch function and the resource growth function intersect twice. However, only the second intersection represents a stable steady state equilibrium with a resource stock of S_A .

3.5 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 I am interested in the effect of exports on the domestic fishery, I model trade as an exogenous increase in the resource price $p^* > p_A$.⁴ I assume that the country is in the autarky steady state when it first opens up to trade and investigate the dynamics starting at this point.

3.5.1 Short-term pattern of production and trade

When a country opens up to trade and $p^* > p_A$, fishing is initially more lucrative than manufacturing and the country specializes in fishing. A comparison of the marginal value product in both industries reveals why the country specializes in fishing. 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^* , the marginal value product of labour in fishing exceeds the marginal value product in manufacturing, which is fixed at 1.⁵ Hence, the country specializes in fishing.

Specialization implies that the country's entire labour force is employed in the fishing industry. Therefore, short-term catch under specialization is given by

$$H_s = \alpha L_T S, \quad (8)$$

where H_s is called the "specialized catch function". It is represented by the upward-sloping segment of the red curve in Figure 1.

³An analytical solution for the autarky steady state stock and price is available in Section 9.3 in the Appendix.

⁴The country specializes in manufactures and imports fish if $p^* < p_A$. If $p^* = p_A$, the pattern of trade is indeterminate.

⁵The marginal value product in manufacturing is 1. Since the economy is diversified in autarky, the marginal value product in manufacturing, $p_A \alpha S_A$, must also be one. When the price increases to $p^* > p_A$, $p^* \alpha S^T > p_A \alpha S_A = 1$.

Catch increases instantly when the country opens up to trade, since the number of workers in the fishing industry increases from βL_T to L_T . This increase in catch is captured by a move from H_A to H_1 in Figure 1.

At H_1 , catch exceed the resource growth rate. Therefore, the stock must decline over time. Since catch is a function of the stock size as described in Equation 8, catch declines as the stock shrinks.

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 diversified steady state and the collapse of the fishery are discussed in the following sections. A discussion of the specialized steady state is deferred to section 9.4 in the Appendix, since specialization in the steady state only occurs if the steady state fish stock can sustain the entire labour force at a wage rate $w > 1$. This is only possible if a country's fishing capacity is low relative to the resource growth rate.

3.5.2 Diversified steady state

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 $p^* \alpha S^\tau = 1$. Rewriting this equation yields the steady state stock in the open economy as a function of the exogenous world market price

$$S_T = \left(\frac{1}{p^* \alpha} \right)^{\frac{1}{\tau}}. \quad (9)$$

The bottom panel of Figure 1 shows all price-resource stock combinations which yield a diversified pattern of production. The steady state resource stock in the open economy is indicated by S_T .

Steady state catch at S_T is represented by H_T in Figure 1. At H_T , the country employs a share γ , with $\beta < \gamma < 1$, of its workforce in the fishing industry, such that catch with γL_T workers exactly equals the resource growth rate.

It is possible to show that the country exports fish both along the transition path and in the diversified steady state. Along the transition path, the country only produces fish. Since workers consume both products, the country must export fish and import manufacturing products. A similar reasoning applies to the steady

state. The economy employs a fraction γ of its workforce in manufacturing, but the workers only spend a fraction $\beta < \gamma$ of their income on fish. Therefore, the excess supply of fish is exported and the country imports manufacturing products.

Exporting leads to an unambiguous reduction in the stock size. As soon as the country opens up to trade, catch exceeds resource growth and the stock must decline. If the economy is diversified in the steady state, the relative reduction in the steady state resource stock can be described as

$$\frac{S_T}{S_A} = \left(\frac{\frac{1}{p^* \alpha}}{\frac{1}{p_A \alpha}} \right)^{\frac{1}{\tau}} = \left(\frac{p_A}{p^*} \right)^{\frac{1}{\tau}} < 1. \quad (10)$$

If $p^*/p_A > 1$, the stock is smaller in the open economy than under autarky. Equation 10 also shows that exporting is more detrimental to schooling fish species for which τ is small. An exogenous increase in the price leads to a larger reduction in the resource stock if τ is small and the catch is not very responsive to the stock size.

These results can be summarized as predictions for the empirical analysis:

Prediction 1. *An exogenous increase in the price leads to*

1. *an instantaneous increase in exports and*
2. *a smaller resource stock in future periods.*
3. *The stock shrinks more if fish species form schools.*

Parts 1 and 2 of the prediction were already shown by [Brander and Taylor \(1997a\)](#) and follow through in the generalized model.

3.5.3 Fisheries collapse as a result of trade

This section shows that a fishery can collapse at very high world market prices. The dynamics leading to this collapse are illustrated by the red dashed line in [Figure 1](#). Given the world market price $p_c > p_A$, the country specializes in fishing when it opens up to trade. Following the same logic as in the previous section, the country 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 1.

However, resource growth is negative at S_c since the stock is smaller than the minimum viable stock size \underline{S} . Therefore, 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. This shows that a fishery, which is sustainable in autarky, can collapse when the country opens up to trade and the price of fish is high.

Yet, a collapse can only occur if the specialized catch function, depicted by the red line in Figure 1 and the resource growth curve do not intersect at any positive stock level. If they intersect, the stock shrinks to S_z at high prices. Figure 6 in the Appendix shows that S_z is the stock at which catch under specialization equals resource growth. The stock cannot decline beyond S_z . If the stock were to decline slightly more, resource growth would exceed catch and the stock would recover. Therefore, S_z is the minimum viable stock size in this setup. Since S_z is also the specialized steady state, this is discussed in more detail in Section 9.4 in the Appendix.

When is a collapse likely to happen? A collapse can only happen if the world market price is high, i.e. $p_c \geq 1/(\alpha S^T)$. Moreover, it is only possible if the country has the capacity to catch fish in excess of resource growth for any positive stock level. This is the case if fishing capacity is high relative to the resource growth rate. Advanced fishing technology or a larger labour force which can participate in fishing rotate the catch function outward and facilitate a collapse at high world market prices.⁶ This result is captured by the following prediction, which guides the empirical analysis:

Prediction 2. *The fishery can collapse at high world market prices if fishing capacity is sufficiently high relative to the resource growth rate.*

To summarize, the theoretical model shows that an exogenous increase in the price leads to an instantaneous increase in fishing and in exports. In the long term, exporting leads to a smaller fish stock. At high world market prices, the fishery can collapse even though it would be viable in autarky.

The model presented above describes a country which moves from autarky to free trade. However, the same results follow through when a diversified small economy is already (partly) open to trade and experiences an exogenous increase in the price. This increase in the price could be due to a reduction of remaining trade barriers or due to a positive export demand shock. The identification strategy of this paper makes use of both an export demand shock originating from Japan and changes in trade barriers to show how exports can lead to the collapse of fisheries.

⁶A formal analysis of the parameter values, for which a collapse is possible, is available in Section 9.5 in the Appendix.

4 Empirical strategy: Collapse of Japanese fisheries as an instrument

This section shows how I estimate the causal effect of fisheries exports on the likelihood of a fishery's collapse. The coefficient estimate for exports is biased downwards in a naive OLS regression of fisheries collapse on exports, since both a collapse and exports are functions of the fish stock. However, the latter is not observed. To address this endogeneity, the collapse of Japanese fisheries is used as an instrument for fisheries exports in countries which 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. In line with the theoretical model, this paper shows that the export demand shock raises exports and can lead to a collapse of a fishery. The empirical strategy ensures that trade is the only channel via which a collapse in Japan can affect the collapse of a fishery in another country.

4.1 Estimating equation

This paper estimates the effect of exports on the likelihood of a fishery's collapse. Exports are considered endogenous and the source of the bias as well as the instrumental variable are discussed in the following sections. Here, I present the estimating equation.

The dependent variable, Collapsed_{ikt} , is a dummy variable, which takes the value of 1 if fish species i has collapsed in country k in year t . Due to the sparsity of stock data, this paper uses a common approach in the literature (see e.g. [Worm et al., 2006](#); [Costello et al., 2008](#)) and defines a fishery as collapsed if catch is below 10 percent of the maximum catch recorded since 1950.

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 low. This implies that landings and exports are low as well. Hence, the causality is likely to run from the collapse to exports once the fishery has collapsed. Since data on exports in collapsed fisheries are not informative about the causal effect of exports on a fishery's collapse, they are not used for the analysis.

Fisheries which have recovered 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 which do not collapse are observed until the end of the sample period.

The dependent variable captures the conditional probability of collapse, since fisheries are only observed up to the point in time at which they collapse. It reflects the probability of a fishery's collapse in time period t , conditional on the fishery not being collapsed in time period $t - 1$. To facilitate the language, this paper refers to this conditional probability as the likelihood of a fishery's collapse.

I model the likelihood 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 vector of control variables "Controls_{ikt}", of region-year fixed effects γ_{rt} , country fixed effects γ_k , species fixed effects γ_i and an error term ϵ_{ikt} . This yields the following estimating equation

$$\text{Collapsed}_{ikt} = \beta_0 + \beta_1 \ln(\text{Exports})_{ikt-1} + \beta \text{Controls}_{ikt} + \gamma_{rt} + \gamma_i + \gamma_k + \epsilon_{ikt}. \quad (11)$$

An increase in exports will only manifest itself as a reduction in the stock size or a collapse in future periods. Therefore, it is necessary to use lags of exports as predictors of fisheries collapse. The baseline specification uses exports in year $t - 1$ as regressor. This captures the short-term effect of exports on the likelihood of a collapse in the following period. Long-term effects and dynamics are discussed and estimated in the sensitivity analysis in Sections 7.4 and 7.5.

In order to net out price effects, I use the export quantity rather than the export value as regressor. The collapse of a fishery in a major seafood market like Japan drives up the price of the respective fish species due to a lower supply on the world market. As a result, the export value of the affected species could increase even though the export quantity stays the same. The use of export values would overstate the extent to which exports react to the collapse of a Japanese fishery.

Since the dispersion of the export quantity is very skewed, this paper uses the natural logarithm of exports as a regressor. The sample, thus, only includes observations with positive trade flows which, in turn, implies that the analysis focuses on the intensive margin of trade. In other words, this paper investigates whether an increase in the volume of fisheries exports raises the likelihood of a fishery's collapse. The question whether countries start exporting as a result of the Japanese collapse and how this affects their fish stocks is not analysed in this paper since data on zero

trade flows are incomplete.

Exports are certainly not the only cause of fisheries collapse. Domestic fisheries management is likely to be a key determinant of a fishery's sustainability. Particularly catch share programs have been shown to significantly reduce the likelihood of fisheries collapse (Costello et al., 2008). Catch share programs are fisheries management tools which allocate secure fishing privileges to individual entities. Most of the catch share programs are individual transferrable quotas (ITQs) or similar quota-based programs. But a small percentage of catch share programs is area-based and allocates the privilege to fish in specific areas to groups or individuals. These programs are called Territorial Use Rights for Fishing programs (TURFs). Since catch share programs such as quotas could also affect exports via a reduction in supply, the empirical model includes the control variable "Catch share_{ikt-1}" which takes the value of 1 if a fishery is regulated using a catch share program.

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

A set of species fixed effects captures all time-invariant species characteristics which could affect the likelihood of a collapse. Those characteristics include the species' fecundity and growth rate. Moreover, I control for time-invariant country characteristics, such as the preference for fish using country fixed effects. Standard errors are clustered at the species level.

Since the dependent variable is binary, I estimate a limited probability model as advocated by Angrist and Pischke (2009). There are several reasons to choose a limited probability model over a nonlinear binary dependent variable model such as logit or probit. Firstly, Angrist and Pischke (2009) point out that 2SLS models estimate average local treatment effects even if the dependent variable is binary. Secondly, LPMs require fewer functional form and distributional assumption and they offer a straightforward interpretation of the coefficient estimates as marginal effects. Finally, much of the real world experience suggests that the estimated marginal effects from linear probability models are similar to those of binary dependent variable models (Angrist and Pischke, 2009). Considering the difficulties in implementing a non-linear model with a large number of fixed effects and instrumental variables, this paper uses a limited probability model.

4.2 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 which could cause a collapse. At the same time, a small stock S_{t-1} implies a small catch and low export volumes in period $t - 1$.

4.3 Collapse of Japanese fisheries as an instrument

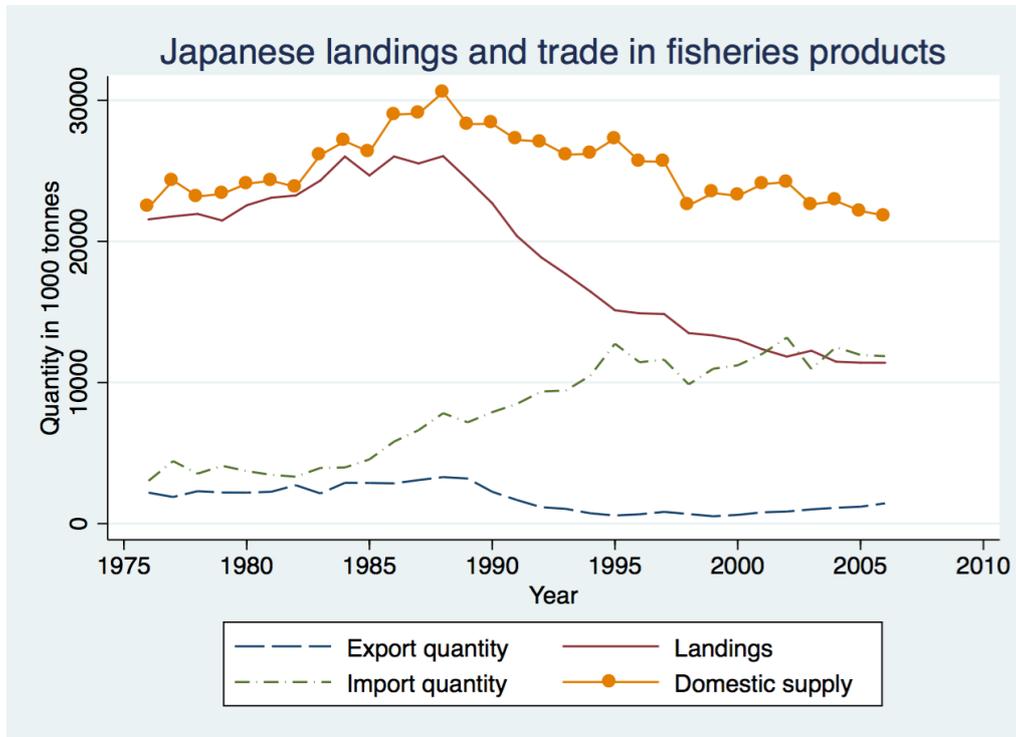
To address this endogeneity, the collapse of Japanese fisheries is used as an instrument for fisheries exports in countries which do not share stocks with Japan. I argue that the collapse of a fishery in Japan has a strong influence on exports in other countries, since Japan is a large seafood market. 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 and spurs exports in the rest of the world. Therefore, a collapse in Japan generates an export demand shock in other countries. The data confirm that this mechanism is at work.

Data from the FAO food balance sheets underpin the importance of Japan as a market for seafood products. Japan was the largest market for seafood products until 1988 and it consumed about 15% of global supply of fishery products up to the late 1980s. This share declined to less than 10 percent with the rise of China as a major market.⁷ In absolute terms, however, domestic supply (defined as production+exports+imports+stock changes) of fishery products in Japan only declined slightly. The yellow connected line in Figure 2 shows that domestic supply exceeded 20 million tonnes throughout the sample period.

The availability of fishery products on the Japanese market was relatively stable,

⁷This 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, since Chinese landings statistics are likely to be overreported (see e.g. [Pang and Pauly, 2001](#); [Watson and Pauly, 2001](#); [Pauly et al., 2014](#)).

Figure 2: Japanese landings and trade in fishery products



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

since an increase in Japanese imports made up for a reduction in domestic catch. Figure 2 shows that landings declined starkly between 1976 and 2006. This reduction in landings is likely to be due to the collapse of fish stocks. Our data show that the percentage of collapsed fisheries in Japan increased from 14 percent in 1976 to 32 percent in 2006. At the same time, Japanese imports soared to the extent that Japan became the second largest importer of seafood products from 1987 onwards.

The instrument is based on the rationale that the surge in Japanese import demand for the collapsed species prompts an increase in the world market price. In our sample a collapse in Japan is, indeed, associated with an increase in the price of the affected species by 7 percent in exporting countries.⁸ This increase in the world

⁸To show that a collapse in Japan raised the world market price, I regress the natural logarithm of the price on the collapse of a fishery in Japan. I control for the existence of a catch share program, species fixed effects, country fixed effects and region-year fixed effects. The sample covers the same observations as the baseline regression. Country-species-year level price data are from Swartz et al. (2012), who collect a comprehensive dataset of ex-vessel prices and estimate missing price data. In the sample used for this paper, about two thirds of the price

market price is expected to raise exports in the rest of the world and the first stage regression, which is discussed in Section 6.2, substantiates this.

4.4 Exclusion restrictions satisfied

The instrument is only valid if trade is the only channel via 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 which 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.

Since neighbouring countries are likely to share fish stocks, all countries with Exclusive Economic Zones adjacent to Japan are excluded from the sample.⁹ The sample does not include Russia, North and South Korea, China, Taiwan, the Philippines and the Northern Mariana Islands.

Some species migrate large distances and might, thus, be fished by Japan and and more remote countries which are not excluded from the sample. Therefore, the sample does not include fish species which migrate large distances (e.g. tunas) and species which have extensive distributions in the high seas. To be precise, I exclude highly migratory fish species listed in Annex 1 of the UN Convention of the Law of the Sea (UN General Assembly, 1982) as well as high sea fish species and all straddling fish stocks¹⁰ in the area surrounding Japan (FAO fishing area 61). A list of the latter two groups is based on (Maguire et al., 2006).

Moreover, I use a collapse in Japan in year $t - 1$ as an instrument. Using the lag of the Japanese collapse should further reduce the risk that unobserved shocks, such as short-term fluctuations in climatic conditions like El Nino, simultaneously affect fisheries in Japan and in the exporting country.

Major climatic events which affect fisheries beyond the countries which are excluded from the sample are picked up by region-year fixed effects. Hence, they do not

data are estimated. Therefore, they are not used for the remainder of the analysis. The results in Column 1 of Table 11 in the Empirical Appendix show that the collapse of a Japanese fishery is associated with an increase in the price of the affected species by 7 percent.

⁹Exclusive Economic Zones 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.

¹⁰Straddling fish stocks are stocks which occur both within a country's exclusive economic zone and beyond it.

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.

5 Data

This section describes the construction of the dataset and provides summary statistics.

5.1 Data on fisheries collapse

A fishery's collapse is inferred based on catch data, which map species level catch to each country's Exclusive Economic Zones. The catch data are from the Sea Around Us catch database, which is described in detail in [Watson and Kitchingman \(2004\)](#).¹¹ The dataset contains information on catch for almost all countries in the world and more than thousand species. It covers the time period from 1950 to 2006.

5.2 Trade data

Disaggregate trade data for almost all countries are available from the FAO Fisheries Commodities Production and Trade Statistics for the years 1976 to 2009. The trade data are matched with the catch data at the country-species-year level. There is no existing concordance table for the landings statistics and the trade statistics. Hence, this table was constructed in the process of the research undertaken for this project.

Two characteristics of the trade data are worth highlighting. Firstly, the dataset distinguishes between different ways in which the fish is processed. 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. To obtain exports at the country-species level, the data are aggregated over all of these different categories for each species in each country.

Secondly, exports are recorded at the species level for some kind of fish like Atlantic cod and European plaice. For other species, the trade statistics are reported in more aggregate categories, like "Mussels". The category "Mussels" includes a whole range

¹¹This paper uses the same data as [Swartz et al. \(2012\)](#). Those data were made available to me by the Institute for the Oceans and Fisheries at UBC and I thankfully acknowledge their cooperation.

Table 1: Summary statistics

	(1)	(2)	(3)	(4)
	Mean	Overall Sd.	Between Sd.	Within Sd.
Collapsed	0.046	0.210	0.137	0.190
Export quantity (lag)	10.213	38.988	25.284	22.746
Export quantity (lag, ln)	6.595	2.671	2.618	1.109
Catch share (lag)	0.103	0.305	0.216	0.190
Collapsed Japan (lag)	0.128	0.334	0.247	0.237
Observations	8919	8919	8919	8919

Between Sd: Standard deviation between country-species combinations

Within Sd: Standard deviation within country-species combinations

of species and the catch data would generally provide more disaggregate information. Since it is not possible to know which of the species in the catch data are exported, export data for aggregate categories like "Mussels" are not used for the analysis in this paper.

5.3 Fisheries management data

Data on catch share programs are from the Environmental Defense Fund (EDF). A few countries have different regulations for different segments of their fishing fleet, based on the length of the vessel, the gear type or the part of the coast the vessels fish in. Species i is recorded as managed in country k as soon as country k adopts a catch share program for part of its fishing fleet which targets species i .

For the empirical analysis, it is important to know when the catch share program was adopted. When this information is missing in the EDF dataset, I use information from government websites and scientific articles. Moreover, I contacted the respective governments to find out when the catch share program was introduced.

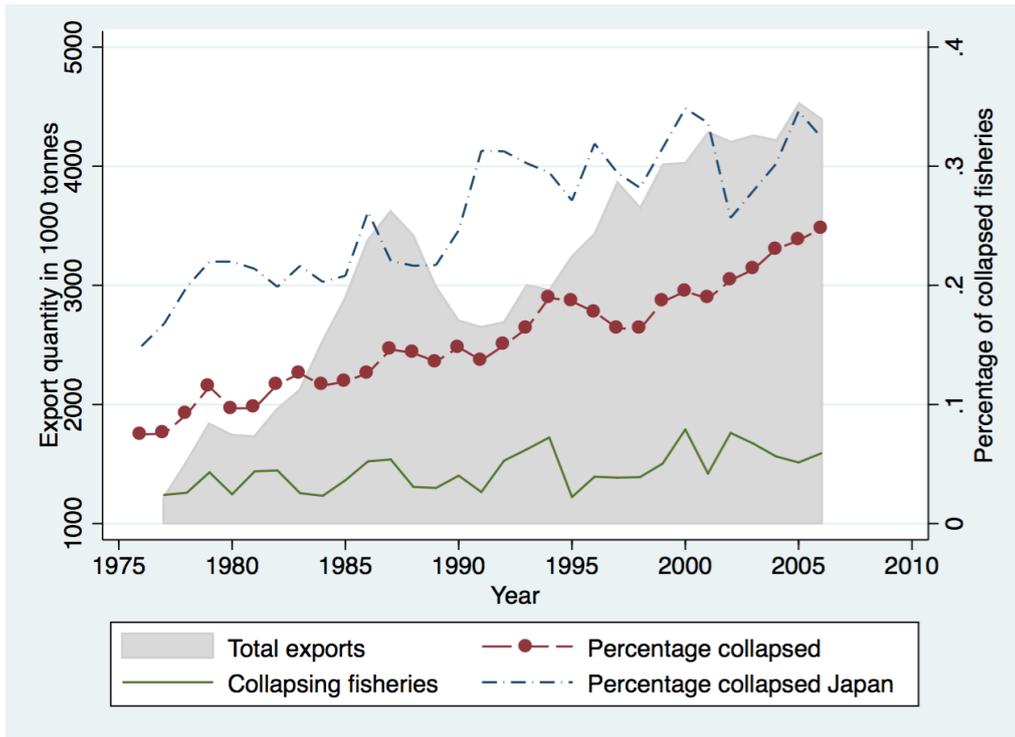
5.4 Summary statistics

This section presents summary statistics and shows that the patterns in the raw data are in line with the predictions of the theoretical model presented in Section 3.

The summary statistics in Table 1 show that 4.6 percent of the observations represent collapsing fisheries. Those are the fisheries in the year of the collapse. Fisheries collapse throughout the sample period. The red line in Figure 3 indicates that the percentage of collapsing fisheries in the sample varies between 2 and 8

percent per year. As a result of this constant depletion of fisheries, the total percentage of collapsed fisheries increases from 7 percent in 1976 to 25 percent in 2006. This is shown by the blue connected line in Figure 3. The percentage of collapsed fisheries is calculated using data on all collapsed fisheries even those which are not used for the empirical analysis.

Figure 3: Fisheries collapse and export quantities in the sample

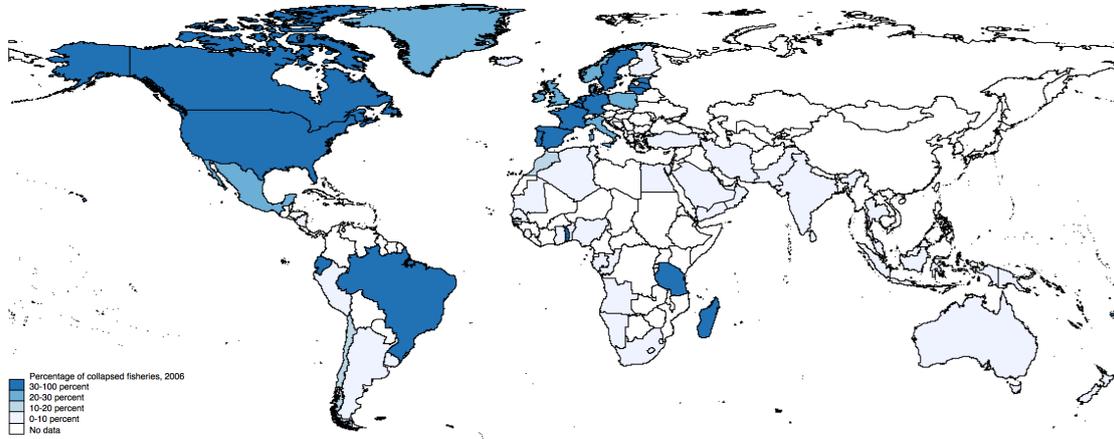


Note: Collapsing fisheries are fisheries the year in which they collapse.

There is significant geographical variation in the depletion of fisheries. The map in Figure 4 shows the percentage of collapsed fisheries in 2006 for every country in the sample. The highest percentage of depleted fisheries can be found in Europe or North America, whereas fisheries in Africa fare better. A significant proportion of Japanese fisheries is depleted. The green dashed line in Figure 3 reveals that the percentage of collapsed fisheries in Japan surges from 14 percent in 1976 to 32 percent in 2006. Table 1 shows that about 12.8 percent of the observations in the sample record a collapse of the same species in Japan in the previous year.

The increasing prevalence of fisheries collapse coincides with a rapid expansion of fisheries exports. The total export quantity of fishery products in the sample

Figure 4: Percentage of collapsed fisheries in 2006



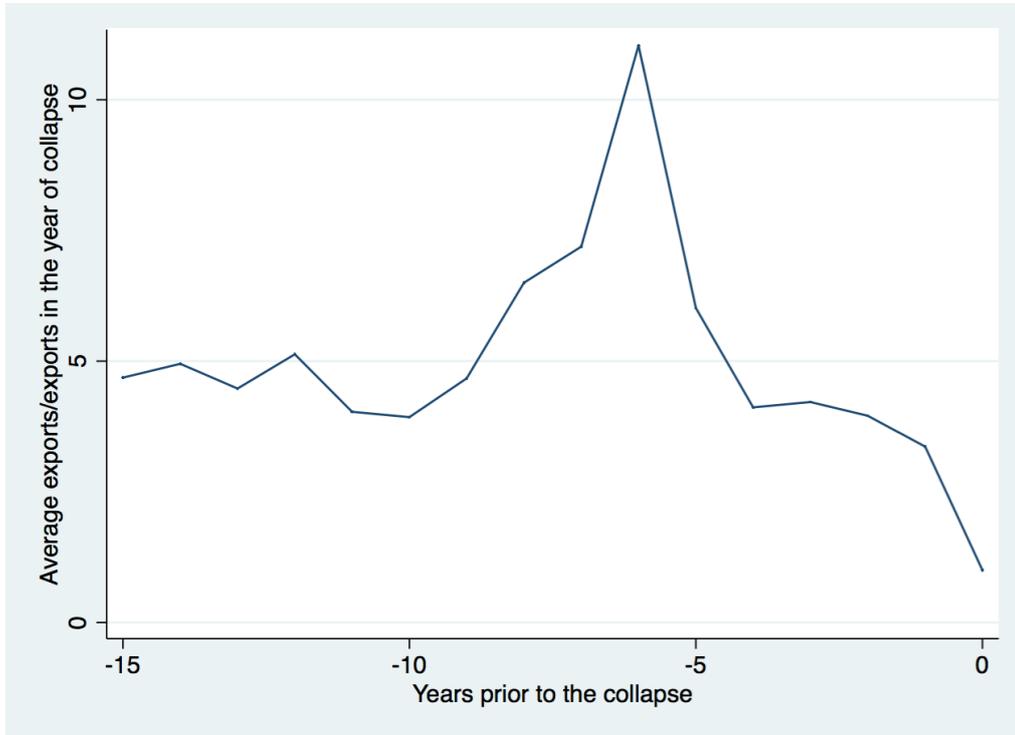
Note: This map is based on the fisheries in the sample. It does not represent all fisheries globally.

used for this study grew by around 265 percent from 1.2 million tonnes of exports in 1976 to 4.4 million tonnes in 2006 (see Figure 3). Total exports of all fishery products, including export of species which are not in the sample grew by almost 400 percent over the same time period. The summary statistics in Table 1 show that, on average, a country exports 10,000 tonnes of a particular fish species per year. However, the export quantity varies considerably (see Column 2 for the overall standard deviation). Due to outliers with very high export quantities, the baseline specification uses the natural logarithm of the export quantity.

Do these data suggest that exports increase prior to a fishery's collapse? To shed light on this question, I normalize exports to 1 in the year of the collapse and graph average exports in year x prior to the collapse relative to exports in the year of the collapse.

Figure 5 suggests that, on average, exports peak a few years prior to the collapse and decline as the fishery is depleted. This is in line with the predictions of the theoretical model, according to which catch and exports would increase temporarily due to a trade liberalisation but then decline when the fish stock shrinks.

Figure 5: Development of exports prior to the collapse of the fishery



6 Results: Exporting leads to the collapse of fisheries

The results in this section show that estimates from an OLS regression are biased downward. Using the collapse of Japanese fisheries as an instrument for exports reveals that exporting significantly raises the likelihood of a fishery's collapse. The effect is larger when fisheries are not regulated via catch share programs. Moreover, the results confirm the prediction from the theoretical model that exporting is more harmful for schooling fish species.

6.1 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 2 suggests that an increase in exports by one percent reduces the likelihood of a fishery's collapse in the following period by 0.004 percentage points. The negative relationship between exports and the fishery's collapse is counterintuitive but, as discussed in Section 4.2, it may be due to a downward bias

Table 2: OLS and baseline results

	(1)	(2)	(3)
	OLS	1st stage	IV
Dependent variable:	Collapsed	Exports	Collapsed
Export quantity (lag, ln)	-0.004** (0.002)		0.087** (0.037)
L.Col. Japan		0.258*** (0.083)	
L.Catch share	-0.012 (0.011)	0.483** (0.202)	-0.055* (0.031)
Prev. Col	0.061*** (0.009)	-0.760*** (0.164)	0.131*** (0.033)
Year FE	Yes	Yes	Yes
Species FE	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
IV			L.Col. Japan
1st stage F-Stat			9.904
Anderson-R. p-value			0.006
Observations	8980.000	8980.000	8980.000

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

of the coefficient estimate. The result from the instrumental variable regression in the next sections confirm this.

6.2 Are the instruments strong?

Prior to the discussion of the 2SLS results, it is necessary to assess the quality of the instrument. This section highlights that the collapse of fisheries in Japan is a sufficiently strong instrument for exports from countries which do not share stocks with Japan. This is important, since it is well known that the 2SLS estimates are biased in the direction of the OLS estimates if instruments are weak.

The first stage regression reveals a strong positive relationship between the collapse of a Japanese fishery and other country's exports of the same species. Column 2 of Table 2 shows that the collapse of a Japanese fishery is associated with an increase

in exports from other countries by 25.8 percent. The coefficient estimate for the export quantity is statistically significant at the 0.1 percent level, suggesting a strong positive conditional correlation between the two variables.

A more formal assessment of the strength of the instrument is possible based on the test by Stock and Yogo (2005). This test shows that the instrument is strong since the null-hypothesis that the asymptotic bias of the 2SLS bias exceeds 15% of the OLS bias can be rejected. Moreover, Staiger and Stock (1997) suggest a rule of thumb according to which instruments are weak if the first-stage F-statistic is lower than 10. The Kleibergen-Paap F-statistic of 9.9 in the baseline model is just at that threshold.¹²

Since the instruments are just at the threshold of being sufficiently strong, this paper reports weak instrument robust hypothesis tests for all regressions. This is crucial since hypothesis tests and confidence intervals can be wrong when instruments are weak (see e.g. Stock et al., 2002). However, Anderson and Rubin (1949) provide a test of structural parameters which is fully robust to weak instruments. This test can be used to assess the statistical significance of the endogenous variable "L.ln(Exports)". The penultimate column of all results tables in this paper is labelled "Anderson-R. p-value" and shows the p-value for the test of the joint null-hypothesis that $\beta_1 = 0$ and that the orthogonality conditions are valid. When this p-value is below 0.1, the coefficient estimate for the export quantity is significant even when the instruments are weak.

It is worth highlighting that weak instruments would not invalidate the results presented in this paper. With weak instruments, the coefficient estimate for the export quantity would be biased downward in the direction of the OLS coefficient estimate. If we worry about weak instruments, we have to think of the coefficient estimates presented here as the lower bound of the effect of exports on the collapse of fisheries.

6.3 IV results: Exporting leads to the collapse of fisheries

The baseline instrumental variable results reveal that exports significantly contribute to overfishing. Column 3 of Table 2 shows that an increase in exports by one percent raises the likelihood of a fishery's collapse in the following year by 0.087 percentage

¹²Since standard errors are clustered, this paper reports the Kleibergen-Paap F-statistic as the relevant first stage F-statistic in all results tables.

points. The effect is large once we take the variation in exports into consideration. The likelihood of a collapse increases by 23 percentage points or about one standard deviation, when logged export increase by one standard deviation.

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 144 percent between 1976 and 2006. According to the estimates, this export boost raised the likelihood of a collapse by around 12.5 percentage points. Since the percentage of collapsed fisheries increased by 18 percentage points over the course of the sample period, the predicted increase in the likelihood of a collapse is equivalent to about two thirds of the observed cases of fisheries depletion. However, these numbers have to be interpreted with caution since they extrapolate an estimated short-term effect over a time period of 30 years.¹³

The findings also provide tentative evidence for a serial fisheries depletion due to trade. Based on the results from the reduced form regression, the collapse of a Japanese fishery raises the likelihood of a collapse in a non-neighbouring country by $0.258 \times 0.087 = 2$ percentage points. This paper only captures one link in a potential chain of resource collapse. If trade leads to sequential fisheries depletion beyond this first link, it could be more damaging for the oceans than the estimates in this paper suggest.

6.4 The effect is larger in fisheries without fishing quotas

The theoretical prediction that exporting can lead to a collapse applies to open access fisheries. However, some of the observations in the dataset are managed via quotas and other rights-based fisheries management tools. In the presence of catch limits, exports are likely to respond less to a demand shock from Japan. Moreover, well-managed fisheries are less likely to be overfished as a result of exporting (Brander

¹³Median exports provide a conservative assessment of export growth since they put less weight on outliers with high export growth. An alternative assessment is possible based on average annual export growth rates. The latter can be estimated in a regression of the form $\text{Ln}(\text{Exports})_{ikt} = \alpha + \beta \text{year} + \gamma_{ik}$, where γ_{ik} is a country-species fixed effects. The result presented in Table 10 in the Appendix suggest an average annual growth rate of 4.5 percent. This adds up to an increase in fisheries exports of 277 over the course of the sample period. The estimate from the baseline regressions suggests that export growth of this order of magnitude raised the likelihood of a collapse by around 0.4 percentage points in a given year and by 24 percentage points over 30 years and hence it slightly over-predicts the observed increase in fisheries collapse. However, this may be due to the assumption of constant exponential growth over a 30 year time period.

and Taylor, 1997b).

Therefore, this section investigates whether the effect of exports on the collapse of fish stocks depends on fisheries management. Adding an interaction term between the export quantity and the catch share dummy variable would allow me to test this. However, such a test would require a second instrumental variable. Lacking this second instrument, I split the sample into fisheries which are regulated using quotas or other catch share programs and fisheries which are not regulated via catch share programs.

The results confirm that fisheries which are not managed via catch share programs are more likely to collapse due to exports. Column 1 of Table 3 reveals that an increase in exports by one percent raises the likelihood of a collapse in the following period by 0.11 percentage points in fisheries without catch share programs. The coefficient estimate is larger than in the baseline regression which included both managed and unmanaged fisheries. Exports do not seem to spur a collapse of fisheries which are managed using catch share programs, as demonstrated in Column 2 of Table 3. This result, however, has to be taken with a grain of salt. The Kleibergen-Paap first stage F-statistic of 1.959 indicates that the instruments are weak in this regression. Hence, the results from the IV regression may be biased downwards.

Table 3: Heterogeneous effects

	(1)	(2)	(3)	(4)
	No quota	Quota	Not schooling	Forage
Export quantity (lag, ln)	0.110** (0.047)	-0.093 (0.066)	0.064** (0.029)	0.240 (0.189)
Controls	Yes	Yes	Yes	Yes
Region-Year FE	Yes	Yes	Yes	Yes
Species FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
1st stage F-Stat	8.923	1.920	12.968	2.794
Anderson-R. p-value	0.006	0.082	0.027	0.066
Observations	7985.000	989.000	5757.000	1024.000

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

6.5 Schooling fish species are more seriously affected

The theoretical model predicts a stronger reduction in the stock of schooling fish species as a result of trade. To investigate whether this prediction holds true in the data, I compare forage fish,¹⁴ which swim in schools, to other marine fish and diadromous fish. Diadromous fish, such as salmon, have their habitat both in marine and fresh water.

The results confirm that fish species which form schools are more severely affected by exports than other fish species. Column 3 of Table 3 shows that an increase in exports by one percent raises the likelihood of a collapse by 0.067 percentage point in a sample of non-schooling marine and diadromous fish species. Forage fish are 0.24 percentage points more likely to collapse as a result of a similar increase in exports. The Anderson-Rubin p-value of 0.066 shows that this coefficient estimate is statistically significant based on weak instrument robust inference.

6.6 Do countries have the capacity to overfish?

Section 3 shows that exporting only leads to the collapse of the fishery if fishing capacity is large relative to the fish population growth rate. This section, thus, analyses whether exports raise the likelihood of a collapse more in countries with a large fishing capacity or a slow resource growth rate.

In the theoretical model, fishing capacity is high if the country has a large labour force which could potentially go fishing and if fishing technology is advanced. Lacking data on fishing technology, I proxy fishing capacity with the number of fishermen relative to the length of the coastline. I split the sample along the median into fisheries with either a small or a large number of fishermen relative to the length of the coastline.

In line with the theoretical predictions, the effect of exports on a fishery's collapse seems to be slightly stronger in countries with a large number of fishermen relative to the length of the coastline. The first two columns of Table 4 suggest that an

¹⁴Forage fish are small pelagic fish in the middle of marine food webs, such as herrings, anchovies, and sardines. They are considered to be more susceptible to environmental influence (see e.g. Pinsky et al. (2011); Chavez et al. (2003); Essington et al. (2015); Beverton (1990)). Fishing raises the likelihood of a collapse (see e.g. Beverton (1990); Chavez et al. (2003); Pinsky et al. (2011); Essington et al. (2015)), since forage fisheries can be viable even when stocks are low due to their schooling behaviour. The sample of forage fish covers all fish species in ISSCAAP category 35. This category includes herrings, sardines and anchovies.

Table 4: Fishing capacity and resource growth rate

	(1)	(2)	(3)	(4)
	Many fishers	Few fishers	Low growth	High growth
Export quantity (lag, ln)	0.104 (0.072)	0.075 (0.067)	0.125 (0.087)	0.113 (0.109)
L.Catch share	-0.110 (0.084)	-0.025 (0.026)	-0.108 (0.078)	-0.044 (0.068)
Prev. Col	0.103** (0.043)	0.136** (0.067)	0.214* (0.118)	0.121 (0.080)
Region-Year FE	Yes	Yes	Yes	Yes
Species FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
1st stage F-Stat	4.299	4.012	2.452	0.905
Anderson-R. p-value	0.082	0.099	0.024	0.015
Observations	4421.000	4430.000	3453.000	3241.000

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.

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

increase in exports raises the likelihood of a collapse by 0.1 percentage points in a sample with a large number of fishermen and by 0.08 percentage points in a sample with a small number of fishermen. The coefficient estimates for the export quantity are statistically significant at the 10 percent level based on weak instrument robust inference.

In order to investigate whether the effect of exports on fisheries collapse depends on the resource growth rate, I split the sample along the median into fisheries with a low fish population growth rate and fisheries with a high fish population growth rate. Data on intrinsic fish population growth rates are from the Appendix of [Cheung and Sumaila \(2015\)](#).

The results in Columns 3 and 4 of Table 4 suggest that the effect of exports on the likelihood of a fishery's collapse does not depend on the fish population growth rate. The coefficient estimates for the export quantity is of a similar order of magnitude in a sample of slow growing fish species as in a sample of fast growing fish species.

It is possible that all countries have the capacity to fish in excess of resource growth at any positive stock level. Therefore, the theoretical prediction that exporting only leads to the collapse of a fishery if the fishing capacity is high relative the resource

growth rate may not be relevant in practice. This may explain why I find that exporting leads to the collapse of fisheries even when the number of fishermen is small or the fish population growth rate is high.

6.7 Aquaculture production

The option to harvest a particular fish species from aquaculture production might take pressure of marine capture fisheries. Indeed, there is tentative evidence that species which are suitable for aquaculture production are not pushed to the brink due to exports. This can be shown using aquaculture production data from FAO Fishstat J. Column 1 of Table 12 in the Appendix reveals that the results from the baseline regression follow through if fisheries which report positive aquaculture production are excluded from the sample. An increase in exports by 1 percent is estimated to raise the likelihood of a collapse by 0.09 percentage points in the following period. In fisheries which report both aquaculture and marine capture fisheries production, exports do not seem to push fish stocks into a collapse. However, due to the small sample of less than 400 observations and the small Kleibergen-Paap F-Statistic in the first stage regression, these results may be biased downwards in the direction of the OLS estimate.

7 Sensitivity analysis

This section shows that the results withstand a series of robustness tests. Firstly, I argue that the results are not driven by potential violations of the exclusion restrictions. Secondly, I show that the results follow through if net exports are used as an alternative measure for trade openness. Thirdly, I discuss potential alternative instruments. The end of this section sheds more light on the dynamic relationship between exporting and fisheries collapse.

7.1 No violation of instrument exogeneity

This section discusses three 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 fishing fleet (b) Japanese exports which lead to a collapse in the Japanese fishery (c)

unobserved environmental factors. There is no evidence that any of these channels are at work and influence the results.

7.1.1 The Japanese foreign fishing fleet's catch does not increase due to a collapse in Japan

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 likelihood of a collapse in other countries.

In practise, the Japanese long distance fleet's activities do not invalidate the instrument. Firstly, [Swartz et al. \(2010\)](#) argue that higher operating cost as well as the increasing cost of accessing foreign country's fishing grounds¹⁵ lead to the decline of the Japanese long distance fleet. Currently, the Japanese fleets activity outside of Japan's waters focuses on tuna or takes place in the exclusive economic zones of China, South Korea and Russia, where reciprocal fishing agreements are in place. Since neither tuna nor Japan's neighbours are included in the sample, the foreign fleet's activities do not invalidate the instrument.

Furthermore, there is no evidence that fishing in distant waters increase as a result of a collapse in Japan. To be precise, the data show that a collapse of species i in Japan's EEZ is not associated with an increase in the Japanese fleet's landings of species i outside of the FAO fishing area which surrounds Japan and its closest neighbours.¹⁶

To corroborate the validity of the instrument, I show that the results are follow through if I control for landings by the Japanese foreign fishing fleet. Towards that end, I construct the variable "Foreign fleet landings $_{ikt}$ ", which represents Japanese catch (measured in tonnes) of species i in year t in FAO fishing areas adjacent to

¹⁵Japan would need to sign a fishing agreement with the exporting country in order to fish within the country's exclusive economics zone.

¹⁶To show this, I regress the long distance fleet's total landings on the collapse of species i in Japan in year t , on year fixed effects and species fixed effects. The long distance fleet's landings, "Long distance total catch $_{it}$ ", are measured in tonnes and represent Japanese landings in all FAO fishing areas except the fishing area surrounding Japan. The sample does not include highly migratory and high sea fish stocks. The results in Column 2 of Table 11 in the Empirical Appendix show that a collapse of a fishery in Japan is not associated with an increase in landings in other fishing areas.

Table 5: Instrument exogeneity

	(1)	(2)	(3)	(4)
	Jap. col.	Timing	Northeast	West
Export quantity (lag, ln)	0.083** (0.033)	0.088** (0.044)	0.092*** (0.031)	0.087** (0.036)
L.Foreign fleet landings	-0.001*** (0.000)			
Controls	Yes	Yes	Yes	Yes
FEs	Yes	Yes	Yes	Yes
1st stage F-Stat	10.185	13.001	14.095	10.699
Anderson-R. p-value	0.005	0.022	0.003	0.007
Observations	8980.000	8488.000	8234.000	8439.000

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

country k 's borders.¹⁷ Canada, e.g. is adjacent to FAO fishing areas 21 and 67. Hence, the variable "Jap. landings $_{ikt}$ " for k =Canada measures Japanese landings of species i in year t in fishing areas 21 and 61. Data on Japanese landings in each FAO fishing area are from the FAO's global capture production database. When the database does not show an entry, Japanese landings in the FAO fishing areas adjacent to country k are assumed to be zero.

Controlling for the Japanese long distance fleet's landings does not change the results, as shown in Table 5. An increase in exports by 1 percent is estimated to raise the likelihood of a fishery's collapse in the following period by 0.083 percentage points. This is almost identical to the coefficient estimate in the baseline regression.

7.1.2 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. Theoretically, this would be possible if a collapse in another major market raised the price of exports and Japan responded with an increase in exports to the extent that its own fishery collapsed. This is unlikely to drive the results for several reasons. The main reason

¹⁷The FAO divides the world's oceans into 19 marine fishing areas. A map of the marine fishing areas is available in the Appendix in Figure 7.

is that I only observe fisheries up to the year in which they collapse. Therefore, the estimates are not affected by events which happen as a result of a collapse in the exporting country unless the fishery recovers and reappears in the dataset.

Moreover, it is reasonable to think of Japan as the first (or at least an early link) in a potential chain of serial resource collapse. Japan was one of the first countries to develop large fishing fleets. Hence, Japan had the capacity to overfish before other countries did. The data confirm this. In the entire sample of landings 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. In more than 50 percent of the cases, it was amongst the first three countries in which the species collapsed.

Even if fisheries in other countries collapsed first, feedback effects are likely to be low since Japan was the largest market for fishery products at the beginning of the sample period. A collapse in another country is, thus, unlikely to have a similar effect on the world market price and export demand as a collapse in Japan. Furthermore, Figure 2 shows that Japan exports a small fraction of its landings and was a net importer throughout the sample period. Therefore, it is unlikely that exports caused the collapse of Japanese fisheries.

To make sure that the results are not biased by an effect of a fisheries collapse in the exporting country on the fisheries collapse in Japan, I exclude 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. Since fisheries are only observed up to the point in time in which they collapse, this only affects country-species combinations which collapse and recover.

The results for a regression using this slightly smaller sample are presented in Column 2 of Table 5. The coefficient estimate for the export quantity suggests that an increase in exports by one percent raises the likelihood of a fishery's collapse in the following period by 0.088 percentage points, which is almost identical to the result in the baseline regression.

7.1.3 Environmental drivers

If environmental factors affect large sea areas, the collapse of fish stocks in Japan may be correlated with the collapse of fisheries in other parts of the Pacific. In

the baseline model, region-fixed effects address this problem since they capture all biological and climatic shocks which affect all species in the same way in one region. Moreover, Japan's direct neighbours, which would be affected similar environmental factors, are excluded from the sample.

To further investigate whether unobserved shocks affect both the Japanese fishery and a fishery in the exporting country, this section shows two robustness tests in which Japan's neighbours as well as (a) countries in the Northeast Pacific (i.e. Canada and the US) and (b) countries in the Western Pacific (FAO fishing area 71) are excluded from the sample.

When countries in the Northeast Pacific are excluded from the sample, an increase in exports by one percent is estimated to raise the likelihood of a collapse by 0.09 percentage points (see Column 3 of Table 5). The coefficient estimate is only slightly higher than in the baseline regression, indicating that the results are not driven by biological or environmental spillovers between fisheries in Japan and exporting countries. Since the US is the largest seafood market in our baseline sample, which does not include Japan, China and Russia, it is reassuring that the results follow through in a sample without the US. The Kleibergen-Paap first stage F-Statistic of 14 indicates that the collapse in Japan is a better predictor of exports in the smaller sample. Since the US is a relatively large market for seafood products, exports respond less to a collapse in Japan than in the rest of the world.

Moreover, the coefficient estimate is almost identical to the coefficient estimate in the baseline regression when countries in the West Pacific are not in the sample. This is shown in Column 4 of Table 5. The robustness of the results further corroborates the validity of the instrument.

7.2 Different measures for exports

It is possible that a country both exports and imports the same species. This could be due to processing trade. China, for example has developed into a processing market for U.S. and Norwegian seafood (Roheim, 2005; Asche and Smith, 2009). This section, thus, investigates whether we come to similar conclusions using net exports, defined as exports-imports at the country-species level, as a regressor. Both the short-term effect of an increase in net exports on the likelihood of collapse in the following period and the long-term effect of net exports are discussed here.

The estimated effect of net exports on fisheries collapse is stronger than the effect

Table 6: Net exports as regressor

	(1)	(2)
	Net exp	Prev. net exp.
L.Ln(Net Exports)	0.1565 (0.1279)	
Ln(Max. Net Exp. up to t)		0.0713* (0.0416)
FEs	Yes	Yes
Controls	Yes	Yes
1st stage F-Stat	2.2890	7.6441
Anderson-R. p-value	0.0142	0.0387
Observations	5880.0000	9185.0000

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.

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

of exports. The results in Column 1 of Table 6 suggest that an increase in net exports by one percent raises the likelihood of collapse in the following period by 0.16 percentage points. This is almost twice the effect size found in the baseline regression. Moreover, this coefficient estimate maybe downward biased and underestimate the true effect due to weak instruments (see Kleibergen-Paap first stage F-statistic of 2.88). Since the confidence intervals can be wrong when instruments are weak, it is necessary to use weak instrument robust inference. The low p-value of the Anderson-Rubin (1949) test, displayed in the second-but last row of Table 6, indicates that the coefficient estimate is statistically significant at conventional significance levels.

The long-term effect of net exports on fisheries collapse can be captured by the maximum of a fishery's previous net exports. This regressor is motivated by the theoretical model, which shows that opening up to trade leads to an instantaneous increase in catch and exports. As the stock declines over time, catch and exports decline as well up to the point at which the fishery collapses.¹⁸ The effect of this peak in exports on the likelihood of a fishery's collapse can be captured by the maximum of the fishery's previous net exports.

Column 2 of Table 6 shows that an increase in maximum historical net exports by one percent raises the likelihood of a fishery's collapse by 0.07 percentage points.

¹⁸Dynamics and long-term effects are discussed in more detail in Sections 7.4 and 7.5.

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

7.3 Alternative instruments

This section discusses the robustness of the results to three changes in the instrumental variable. Firstly, import tariffs for seafood products are used as a second instrument. Secondly, 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. Finally, I use a second instrument which captures an increase in export demand for species which are close substitutes to the fish species which has collapsed in Japan.

7.3.1 Seafood tariffs as second instruments

Import tariffs for seafood products in Japan (or other markets) could be used as a second instrument. A reduction in Japanese tariffs should raise Japanese imports and hence spur other countries' exports. The instrument is arguably exogenous since Japanese import tariffs can only affect the collapse of fisheries in exporting countries via trade.

However, the Japanese preferential import tariff¹⁹ at the species level is a weak instrument for exports. The Japanese tariff is not significantly related to exports in the first stage regression. This may be explained by the low time variation of the variable.

The coefficient estimate of 0.03 in the second stage regression is smaller than the coefficient estimate in the baseline regression. This difference could either be due to a downward bias in light of weak instruments or due to the reduction in the sample period to 1988-2006 rather than 1976-2006.

I also tried to use species-level preferential import tariffs in the US, EU or China as instruments. However, neither of these variables is significantly related to exports in other countries in a regression with country fixed effects and species fixed effects.

¹⁹I use data on preferential tariffs at the HS6 digit level from the WITS database. The data are available for the years 1988 to 2006. The preferential tariff at the species level is calculated as the simple average over all HS6 digit tariff lines which apply to the species. The preferential tariff for Atlantic cod, for example, is calculated as the unweighted average over the tariff rate for the categories "fresh or chilled cod", "frozen cod" and "frozen cod meat".

Table 7: Alternative instruments

	(1)	(2)	(3)
	IV tariff	IV distance	Spillovers
Export quantity (lag, ln)	0.030 (0.041)	0.076** (0.035)	0.080** (0.034)
FEs	Yes	Yes	Yes
Controls	Yes	Yes	Yes
IV 1	L.Col. Japan	Col. Japan*distance	L.Col. Japan
IV 2	Tariff Japan	-	L.Col. J. Family
1st stage F-Stat	4.301	7.572	5.037
Anderson-R. p-value	0.069	0.019	0.022
Observations	6145.000	8976.000	8980.000

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.

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

7.3.2 Distance from Japan

It is a well-established empirical fact that trade flows are negatively correlated with distance (see e.g. [Head and Mayer, 2014](#)). Therefore, exports are likely to react less to the collapse of a Japanese fishery if a country is far away from Japan. As a further robustness test, 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 most important cities in terms of 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 likelihood of a collapse by 0.08 percentage points. This coefficient estimate, which is displayed in Column 2 of Table 7, is only slightly smaller than the coefficient estimate in the baseline regression.

7.3.3 Spillovers to other fisheries

This section introduces a second instrument which captures an increase in export demand for close substitutes to the fish species which has collapsed in Japan. Substitution effects may occur since the collapse of a Japanese fishery is associated with an increase in the price of the affected species. It is, thus, possible that

consumers shift their expenditure to close substitutes. As a result of that, import demand for closely related species would increase as well. Such spillovers would bias the coefficient estimate for the export quantity downward in the first-stage regression.

A thorough assessment of these spillover effects would require data on the substitutability of fish species and we are not aware of a good database on this. However, species from the same family are likely to be close substitutes since they share a lot of characteristics. Therefore, we use the variable "Col. J. Family $_{it}$ " as a second instrument. The variable takes a value of 1 if a species which is in the same family as species i has collapsed in Japan in year t .

There is no evidence of substitution effects. In the first stage regression, the coefficient estimate for "Col. J. Family $_{it}$ " is not significant. This indicates that exports of fish species which are in the same family as the fish species which has collapsed in Japan do not increase as a result of the collapse. Moreover, the results in the second stage regression are not affected by the introduction of this second instrument. Column 3 of Table 7 shows that an increase in exports by one percent is estimated to raise the likelihood of a fishery's collapse by 0.08 percentage points. This is very similar to the finding in the baseline regression.

7.4 Dynamics

This section shows that the medium-term and long-term effect of exports on the likelihood of a fishery's collapse is higher than the short term effect which is modelled in the baseline regression. To demonstrate this, longer lags of exports as well as maximum historical exports are used as regressors.

If landings already decline in the year prior to the collapse, exports two years prior to the collapse may be a better predictor of the collapse than exports in the year prior to the collapse. Indeed, the results in Column 1 of Table 8 confirm this. An increase in exports in period $t - 2$ is estimated to raise the likelihood of a fishery's collapse in period t by 0.11 percentage points. This estimated effect is slightly larger than the short-term effect estimated in the baseline regression.²⁰

The theoretical model in Section 3 predicts a temporary peak in catch and exports

²⁰I do not find a significant effect of exports in period $t - 3$ on a fishery's collapse in period t (see Column 3 of Table 8). Exports in period $t - 4$ are estimated to raise the likelihood of a collapse in period t by 0.09 percentage points. In all of those regressions, the collapse of a Japanese fishery in period $t - l$ is used as an instrument for exports in period $t - l$.

as a result of the exogenous increase in the price. Even if the price stays high, exports decline over time as the stock declines. 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 . 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 long-term effect of exports on a collapse from the theory to the data, since the speed at which a fishery transitions to the collapse depends on the fishery's characteristics in the theoretical model.

The results confirm that exporting leads to fisheries depletion in the long-term. Column 4 of Table 8 shows that an increase in maximum historical exports by 1 percent raises the likelihood of a fishery's collapse by 0.11 percentage points. The coefficient estimate is statistically significant based on weak instrument robust inference. The Anderson-Rubin p-value of 0.017 displayed at the bottom of the Table shows that the coefficient estimate is statistically significant.

Table 8: Different lags of exports

	(1)	(2)	(3)	(4)
L2.ln(Exports)	0.105** (0.048)			
L3.ln(Exports)		0.053 (0.077)		
L4.ln(Exports)			0.088 (0.080)	
Ln(Max. Exp. up to t)				0.113 (0.072)
IV	L2.Col. Jap.	L3.Col. Jap.	L4.Col. Jap.	L.Col. Japan
1st stage F-Stat	6.489	2.674	2.325	3.750
Anderson-R. p-value	0.004	0.382	0.098	0.017
Observations	8423.000	7907.000	7430.000	11379.000

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

7.5 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 3 shows that the stock in any period is a function of the stock in the previous period, of resource growth and catch. The use of biomass data allows me to model these dynamics empirically. However, this requires a different empirical strategy. I use 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 scientific stock assessments, where available. Due to the sparsity of stock assessments, these data have to be supplemented with estimates of stock biomass. The results show that exporting is associated with a reduction in stock biomass. This confirms that exports can have a detrimental effect on fish stocks.

7.5.1 Alternative empirical strategy to capture dynamics

The use of biomass data allows me to model the stock dynamics which result from an increase in exports in more detail. I use 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 3, 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 (Equation 12), in which the error term consists of a country-species specific time-invariant component η_{ik} and the time-varying component ϵ_{ikt} . The empirical model includes year fixed effects γ_t and controls for fisheries management via catch share programs, as captured by the variable "Catch share $_{ikt-1}$ ".

$$\ln(S_{ikt}) = \alpha_1 \ln(S_{ikt-1}) + \alpha_2 \ln(\text{Exports})_{ik,t-1} + \alpha_3 \text{Catch share}_{ikt-1} + \gamma_t + \eta_{ik} + \epsilon_{ikt} \quad (12)$$

The short-term effect of exports on biomass is captured by the coefficient α_2 in Equation 12. Based on the theoretical model presented in Section 3, an increase in exports in period $t - 1$ is associated with an increase in catch and will, hence, reduce stock biomass in period t .

The long-term effect of exports on biomass can be calculated as $\alpha_2/(1 - \alpha_1)$. An increase in exports in period $t - 1$ affects the stock in all future periods $t + l$ and $i > 0$, since biomass in all future periods $t + l$ for all $l \geq 1$ is a function of biomass in period t . The effect of an increase in exports in period $t - 1$ on stocks in period $t + 1$, for example, is given by $\alpha_1 * \alpha_2$. Applying the same reasoning to all future period yields an infinite geometric series and, hence, the long-term effect of exports on the stock biomass is given by $\alpha_2/(1 - \alpha_1)$.

Equation 12 is estimated using an Arellano-Bond estimator. The Arellano-Bond model uses the first difference of Equation 12 to eliminate the time-invariant components of the error term, η_{ik} . A consistent estimator can, then, be obtained using lags of $\ln(S_{ikt-l})$, $\ln(\text{Exports})_{ikt-l}$, and Catch share $_{ikt-l}$ for all $l > 2$ as instruments for the first difference equation. Due to the availability of alternative instruments, it is not necessary to use the collapse of Japanese fisheries as an instrument in this section. Details on the construction of the instrument matrix and the data are available in the Appendix in Section 10.1.

7.5.2 Results: Exporting reduces stock biomass

Table 9: Dynamic model for the effect of exports on fisheries collapse

	(1)
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 #	45.000
AR(1) p-value	0.001
AR(2) p-value	0.786
Hansen p-value	0.208
Observations	9362.000
Standard errors (clustered at the country-species level) in parentheses	
* p<0.1, ** p<0.05, *** p<0.01	

The results reveal that exporting significantly reduces stock biomass, both in

the short term and in the long term.²¹ The short-term effect is captured by the coefficient estimate for the export quantity in the first column of Table 9. 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 bottom of table). This corroborates the finding that exporting has a negative effect on fish stocks.

8 Conclusion

This paper investigates the causal effect of fisheries exports on the collapse of fisheries using a 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 in countries which do not share fish stocks with Japan.

The results show that exports have a large negative impact on fisheries. An increase in logged exports by one standard deviation raises the likelihood of a collapse in the following year by 23 percentage points. The effect of exports on the collapse of fisheries is particularly dramatic in light of the rapid growth of fisheries exports over the sample period. Exports for the median fishery grew by 144 percent over the course of the sample period. According to the estimates, this raised the probability of a collapse by around 12.5 percent. The predicted increase in the likelihood of fisheries collapse is equivalent to around two thirds of the observed increase in the percentage of collapsed fisheries. The latter increased by 18 percentage points to the extent that a quarter of the fisheries in the sample had collapsed in 2006.

The results highlight the importance of fisheries management. The estimates show that exporting only causes a collapse of fisheries which are not regulated via quotas or other rights-based fisheries management tools. This finding corroborates the theoretical prediction that exports only lead to overfishing in open access fisheries (Brander and Taylor, 1997b; Chichilnisky, 1994). Hence, the results do not call for trade restrictions but rather for the implementation of sustainable catch limits.

The introduction of sustainable catch limits is particularly important for developing

²¹The 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 9, shows that the null-hypothesis of valid moment conditions cannot be rejected.

countries, which export half of the global export value ([FAO, 2016](#)). In those countries, exports of fishery products are an important source of foreign exchange earnings, income and employment. However, the use of quotas or similar rights-based fisheries management tools is not very wide-spread in the developing world ([Jardine and Sanchirico, 2012](#)). In order to benefit from fisheries exports in the long term, developing countries need to implement sustainable fisheries regulation.

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9 Theory 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

$$u = h^\beta m^{(1-\beta)}. \quad (13)$$

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

$$ph + m = w \quad (14)$$

where w is the worker's wage income. The price of the manufacturing product is normalized to 1 and p is the price of fish. Maximizing utility (13) subject to the budget constraint (14) yields the individual demand for fish $h = \beta w/p$ and manufactures $m = (1 - \beta)w$. Multiplying individual demand by the number of workers in the economy L_T yields the aggregate demand for fishery products

$$H^C = hL_T = \frac{\beta w L_T}{p}. \quad (15)$$

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

$$\frac{w}{p}L_H = \alpha L_H S^\tau. \quad (16)$$

This equation can be used to solve for the open access resource price in Equation 4.

9.3 Autarky steady state

In the steady state equilibrium, catch equals the resource growth rate. Therefore, short-run catch from Equation 7 must equal resource growth from Equation 2:

$$\beta L_T \alpha S^\tau = r [S - \underline{S}] \left[1 - \frac{S}{K} \right]. \quad (17)$$

Equation 17 determines the steady state resource stock. An analytical solution of the general case is not possible but I provide a solution for the case in which $\tau = 1$. Setting $\tau = 1$ and manipulating terms in Equation 17 yields

$$S^2 + DS + \underline{S}K = 0 \quad (18)$$

where $D = (\beta L_T \alpha K)/r - K - \underline{S}$. This second order polynomial has two solutions if $D^2 - 4\underline{S}K > 0$. The two solutions are given by

$$S_1 = \frac{-D - \sqrt{D^2 - 4\underline{S}K}}{2} \quad (19)$$

$$S_A = \frac{-D + \sqrt{D^2 - 4\underline{S}K}}{2}. \quad (20)$$

If both solutions are positive, S_A represents a stable equilibrium. The autarky price can be obtained if S_A is substituted into Equation 4

$$p_A = \frac{2}{-\alpha D + \alpha \sqrt{D^2 - 4\underline{S}K}}. \quad (21)$$

9.4 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. This section first provides an intuitive description of the dynamics leading to the specialized steady state S_z . This is followed by an algebraic solution of the specialized steady state for $\tau = 1$.

The specialized steady state S_z is illustrated in Figure 6. To facilitate the discussion, p_z is defined as the price at which the marginal value product of fishing and manufacturing are equal at stock S_z . p_z is shown in the bottom panel of Figure 6.

What are the dynamics leading to the specialized steady state? Let us assume

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 from H_A to H_1 , as shown in the top panel of Figure 6. 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. The economy remains specialized at S_z , since the marginal value product of labour exceeds the marginal value product of manufacturing at $p^* > p_z$.

A specialized steady state only exists if $p^* \geq p_z$. If the world market price is lower than p_z , the economy diversifies before the stock has declined to S_z following the same logic presented in Section 3.5.2.

The fishery cannot collapse at high prices if the specialized catch function and the resource growth curve intersect at positive stock levels. As explained above, the stock cannot decline further once it has reached S_z . Therefore, S_z is the minimum stock level which is possible in this setup, even at very high resource prices.

I now provide a formal solution for the resource stock in the specialized steady state for $\tau = 1$. In the specialized steady state, all of the labour force is employed in fishing and catch is given by $H = \alpha L S_z$ (setting $\tau = 1$.) Moreover, catch must equal the resource growth rate:

$$L_T \alpha S = r [S - \underline{S}] \left[1 - \frac{S}{K} \right]. \quad (22)$$

Manipulating terms, this equation can be rewritten as

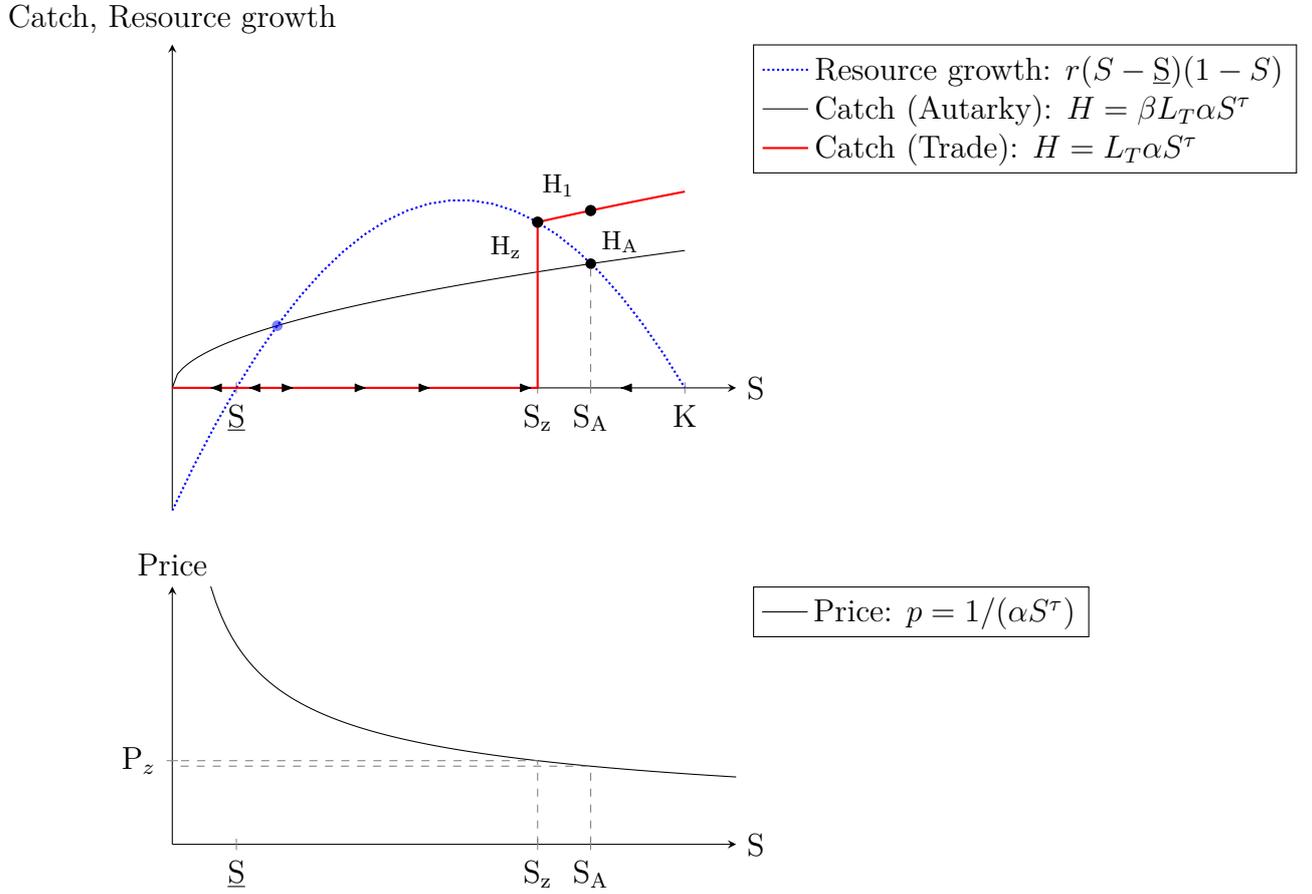
$$S^2 + FS + \underline{S}K = 0 \quad (23)$$

where $F = (L_T \alpha K)/r - K - \underline{S}$. This second order polynomial has two solutions if $F^2 - 4\underline{S}K > 0$. The two solutions are given by

$$S_{z1,z2} = \frac{-F \pm \sqrt{F^2 - 4\underline{S}K}}{2}. \quad (24)$$

If both solutions are positive, $S_{z2} = -0.5F + 0.5\sqrt{F^2 - 4\underline{S}K}$ represents the stable steady state.

Figure 6: Specialized steady state



9.5 Conditions for a collapse to be possible

A fishery collapses if (1) $p_c \geq 1/(\alpha \underline{S}^\tau)$ 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{S} is high and if fish species form schools implying that τ is low.

Condition (2) requires that

$$L_T \alpha S^\tau > r [S - \underline{S}] \left[1 - \frac{S}{K} \right]. \quad (25)$$

Manipulating terms yields

$$S^2 + (L_T \alpha K / r) S^\tau - K S + \underline{S} (K - S) > 0 \quad (26)$$

This condition 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 larger than zero. Therefore, this condition is also more likely to be satisfied when the minimum viable stock size \underline{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 and fish species do not form schools. Overall, it is not clear whether schooling fish species are more or less likely to collapse. This depends on the parameters of the model.

10 Empirical Appendix

Table 10: Average export growth rate within fisheries

	(1)
	Ln(Export quantity)
Year	0.044*** (0.005)
Country-species FE	Yes
Observations	8138.000

Standard errors (clustered at the species level) in parentheses. This table shows results for the regression $\text{Ln}(\text{Exports})_{ikt} = \alpha + \beta\text{year} + \gamma_{ik}$, where γ_{ik} is a country-species fixed effect. The average annual growth rate of trade in fisheries products is $e^\beta - 1 = 0.045$.

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

Table 11: Price effect and long distance fleet landings

	(1)	(2)
	Ln (Price)	Foreign fleet landings
Col. Japan	0.075** (0.035)	-781.931 (1075.277)
Catch share	0.102 (0.065)	
Country FE	Yes	Yes
Species FE	Yes	No
Year FE	Yes	Yes
Region-Year FE	Yes	No
Observations	8980.000	1318.000

Standard errors (clustered at the species level) in parentheses

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

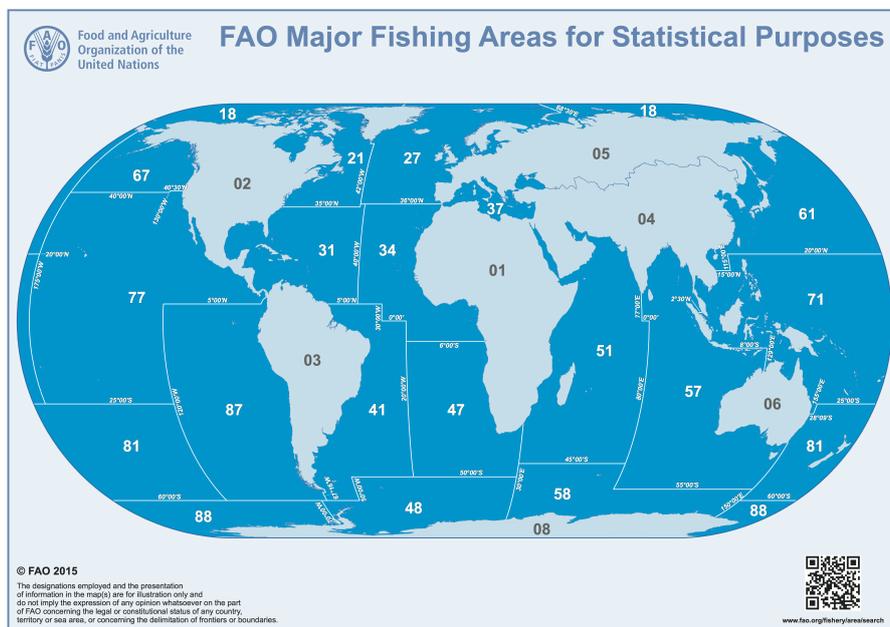
Table 12: Aquaculture

	(1)	(2)
	Aquaculture	No Aqua.
Export quantity (lag, ln)	-0.080 (0.212)	0.087** (0.035)
Controls	Yes	Yes
FEs	Yes	Yes
1st stage F-Stat	1.640	9.877
Anderson-R. p-value	0.660	0.007
Observations	334.000	8644.000

Standard errors (clustered at the species level) in parentheses

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

Figure 7: FAO fishing areas



Source: <http://www.fao.org/fishery/area/search/en>

10.1 Dynamic panel data model of stock biomass

Instrument matrix

When constructing the instrument matrix, the lag of stock biomass, exports and the catch share are considered to be predetermined, implying that they may be correlated with past error terms ϵ_{ikt-l} for all $l > 0$ but not with the contemporaneous error term ϵ_{ikt} . Stock biomass is predetermined by definition, since it is a function of the stock in previous years. In the theoretical model, catch (and thus exports) are functions of the current stock size. Therefore, exports in any time period must also be correlated with past errors. The theoretical model does not provide any guidance concerning the role of catch share programs. However, since a dramatic reduction in biomass has motivated the introduction of catch share programs in several countries (see e.g. [Parsons, 2010](#); [Matthiasson and Agnarson, 2010](#); [Connor and Shallard, 2010](#); [San Martín et al., 2010](#)), the existence of a catch share program is also considered to be a function of past stock biomass and the variable is treated as a predetermined variable.

In Arellano-Bond models, the number of instruments is quadratic in the number of years in the sample. While more instruments improve efficiency, a very large number of instruments is associated with biased coefficient estimates and misleadingly small standard errors. There are two approaches to reducing instrument count in dynamic panel data models. The first one limits the lags of the regressors which are used as instruments. The second approach combines instruments to a smaller set by collapsing the instrument matrix (see [Roodman, 2009](#)). With a collapsed instrument matrix, the moment conditions are $E[y_{ik,t-l}\Delta\epsilon_{ikt}] = 0$ for each $l \geq 2$ and for each of the predetermined regressors y rather than $E[y_{ik,t-l}\Delta\epsilon_{ikt}] = 0$ for each $l \geq 2$, $t \geq 3$. However, the moment conditions reflect the same underlying belief about the instruments.

Since the panel spans almost 30 years, a combination of both approaches is to reduce the instrument count. I only use lags up to 10 years as instruments for the stock biomass and lags up to 3 years for exports and catch share programs. Moreover, the instrument matrix is collapsed.

I use a twostep estimator of the covariance matrix with a [Windmeijer \(2005\)](#) finite sample correction. The latter addresses the potential downward bias in two-step estimates of the covariance matrix. The standard errors presented in this paper are robust to any form of heteroskedasticity and autocorrelation within panels. The

standard errors for the long-term effects of exports on biomass are calculated using the delta method.

Data on stock biomass and exports

This model is estimated using data on total stock biomass from the RAM legacy stock assessment database (Ricard et al., 2012). Since the RAM legacy database only covers around 500 fish stocks, these data are supplemented with estimates of biomass from Costello et al. (2016).²² Costello et al. (2016) estimate stock biomass based on landings statistics using the Catch-MSY method proposed by Martell and Froese (2013).

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, I aggregate to the country level. Aggregation to the country level is necessary since the analysis links developments of stock biomass to country-level export data.

²²I am very grateful to Chris Costello and Tyler Clavelle for access to these data.