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

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In the case of fisheries, exports are an important cause of resource depletion. This paper uses rich country-species-level fisheries data to estimate the causal effect of a fishery's exports on the collapse of the fishery. Identification is based on an export demand shock originating from Japan. The results reveal that an increase in logged exports by one standard deviation raises the likelihood of a fishery's collapse in the following period by 23 percentage points. Only fisheries without fishing quotas collapse as a result of exports.

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1 Introduction

The depletion of renewable resources is becoming ever more prevalent. Forest cover loss in the tropics, fisheries collapse and the endangered status of rhinos and thousands of other animal and plant species are prominent examples (FAO, 2016*a*; Worm et al., 2006; IUCN, 2018). Even though renewable resources are important export products in the developing world, we still have a poor understanding of the extent to which trade contributes to resource depletion. Empirical studies on trade in renewable resources are limited by at least one of the following three factors: lack of causal inference, lack of species level information on trade flows and resource stocks and lack of external validity due to a focus on selected species. Existing research focuses on the effect of trade in forest products (Ferreira, 2004; Tsurumi and Managi, 2014; Faria and Almeida, 2016), ivory (Barbier et al., 1990) and buffalos hides (Taylor, 2011). Causal insights on the effect of fisheries exports on fish stocks are missing.

This paper uses rich fisheries data to estimate the causal effect of fisheries exports on the collapse of fisheries. I employ a novel identification strategy, using an export demand shock originating from Japan as an instrument for exports in the rest of the world. The use of country-species-year level data on trade in fishery products yields detailed insights about the way exports affect the collapse of numerous different fish species. Moreover, the paper highlights the importance of institutions. The results suggest that an increase in exports leads to a large increase in the likelihood of a collapse, especially in fisheries which are not regulated via quotas or other rights-based fisheries management tools.

Fisheries are a particularly interesting resource to study since they are both highly traded and threatened by resource collapse. Fishery products have become one of the most highly traded food commodities and more than one third of global fish production is exported (FAO, 2016*b*). At the same time, the world's fisheries are overfished and 27% of the world's fisheries had collapsed in 2003 (Worm et al., 2006). This begs the question whether exports cause the collapse of fisheries.

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

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

To guide the empirical estimation, I illustrate under which conditions exports cause the collapse of an open access renewable resource which is viable in autarky. I use a Ricardian model similar to Brander and Taylor (1997*a*) and Copeland and Taylor (2006) and I focus on a situation in which a trade liberalization is associated with an exogenous increase in the resource price. This increase in the price makes harvesting more lucrative and, as a result, the country harvests more and exports the renewable resource. Since harvest exceeds resource growth, the resource stock shrinks over time. At high world market prices, exporting can lead to the collapse of an open access renewable resource if harvesting capacity is high relative to the resource growth rate. Resources with stringent harvesting quotas do not collapse as a result of an exogenous increase in the price.

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, Gaines and Lynham, 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 spurs exports in other countries. Therefore, the collapse of a Japanese fishery is positively correlated with exports in other countries. The instrumental variable estimation in necessary since both exports and the likelihood of a collapse in the following year depend on the size of the fish stock, which is unobserved.

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 most other studies in the literature on trade in renewable resources.

The paper shows that exports significantly contribute to the collapse of fisheries. The results suggest that an increase in exports by one percent raises the 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.

I find that exports only lead to a collapse of fisheries which are not regulated through quotas or other rights-based fisheries management tools.[1] Therefore, the results from this paper do not call for trade restrictions for fishery products, but rather for the implementation of sustainable fisheries management. Particularly developing countries which rely heavily on income and export revenue from fisheries would benefit from the adoption of sustainable regulations to guarantee long-term gains from fisheries exports.

This paper contributes to the existing empirical literature on trade in renewable resources in three main ways. Firstly, it estimates the causal effect of exports on the depletion of a renewable resource. Thus far, only Taylor (2011) provides

[1] This is in line with the literature's finding that trade openness leads to the overharvesting of renewable resources, particularly if they are unregulated (see e.g. Barbier et al., 1990; Taylor, 2011; Ferreira, 2004). Please see Bulte and Barbier (2005), Fischer (2010) and Copeland (2011) for more comprehensive reviews of the literature on trade in renewable resources.

convincing causal estimates of the effect of exports of bison hides on the near extinction of the North American bison.

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. Existing papers (see e.g Ferreira, 2004; Faria and Almeida, 2016; Erhardt, 2018) use country level exports+import relative to GDP as a proxy for trade openness. These proxies provide limited information on trade in renewable resources.

Finally, this paper analyses the effect of fisheries exports on the depletion of fisheries, whereas most of the existing literature focuses on other resources. To the best of my knowledge, Erhardt and Weder (2015) and Erhardt (2018) provide the only empirical analyses of the relationship between trade openness and overfishing. However, neither of those papers can quantify the effect of fisheries exports on the depletion of fisheries due to a lack of fisheries trade data.[2] The use of both detailed and comprehensive fisheries trade data and causal inference allows me to remedy short-comings of Erhardt and Weder (2015) and Erhardt (2018)'s papers and, for the first time, estimate the causal effect of exports from a particular fishery on the collapse of that fishery.

This paper is structured as follows. Section 2 illustrates the theoretical background for the analysis. The empirical strategy is presented in Section 3. 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. Section 7 shows that the effect of exports depends on fisheries management and presents further heterogenous effects which are in line with the paper's theoretical hypotheses. This is followed by a sensitivity analysis in Section 8. Section 9 concludes.

[2] Erhardt (2018) investigates the effect of trade openness on the percentage of collapsed species at the country level. He uses country-level exports plus imports relative to GDP and a country-level index for globalization as very crude proxies for trade in fishery products. Erhardt and Weder (2015) find a positive correlation between a shark species' IUCN red list status and a dummy variable, which indicates whether a shark species is traded internationally, but do not provide causal insights.

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

This section uses a simple Ricardian trade model like Brander and Taylor (1997*a*) and Copeland and Taylor (2006) to illustrate under which circumstances exporting can lead to the collapse of a fishery which is viable in autarky. The discussion focuses on a situation in which opening up to trade is associated with an exogenous increase in the price of fish. As a result of this increase in the price, fishing becomes more lucrative and the country instantly produces and exports more fish. Due to this additional fishing pressure, the catch of fish exceeds resource growth and the stock declines over time. At high world market prices, a fishery can collapse if fishing capacity is high relative to the resource growth rate. Fisheries with stringent catch limits do not collapse as a result of trade.

This section provides an intuitive explanation of the way trade affects the fishery. Technical details are deferred to Section 10 in the Appendix.

2.1 Model setup

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.

Prior to 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

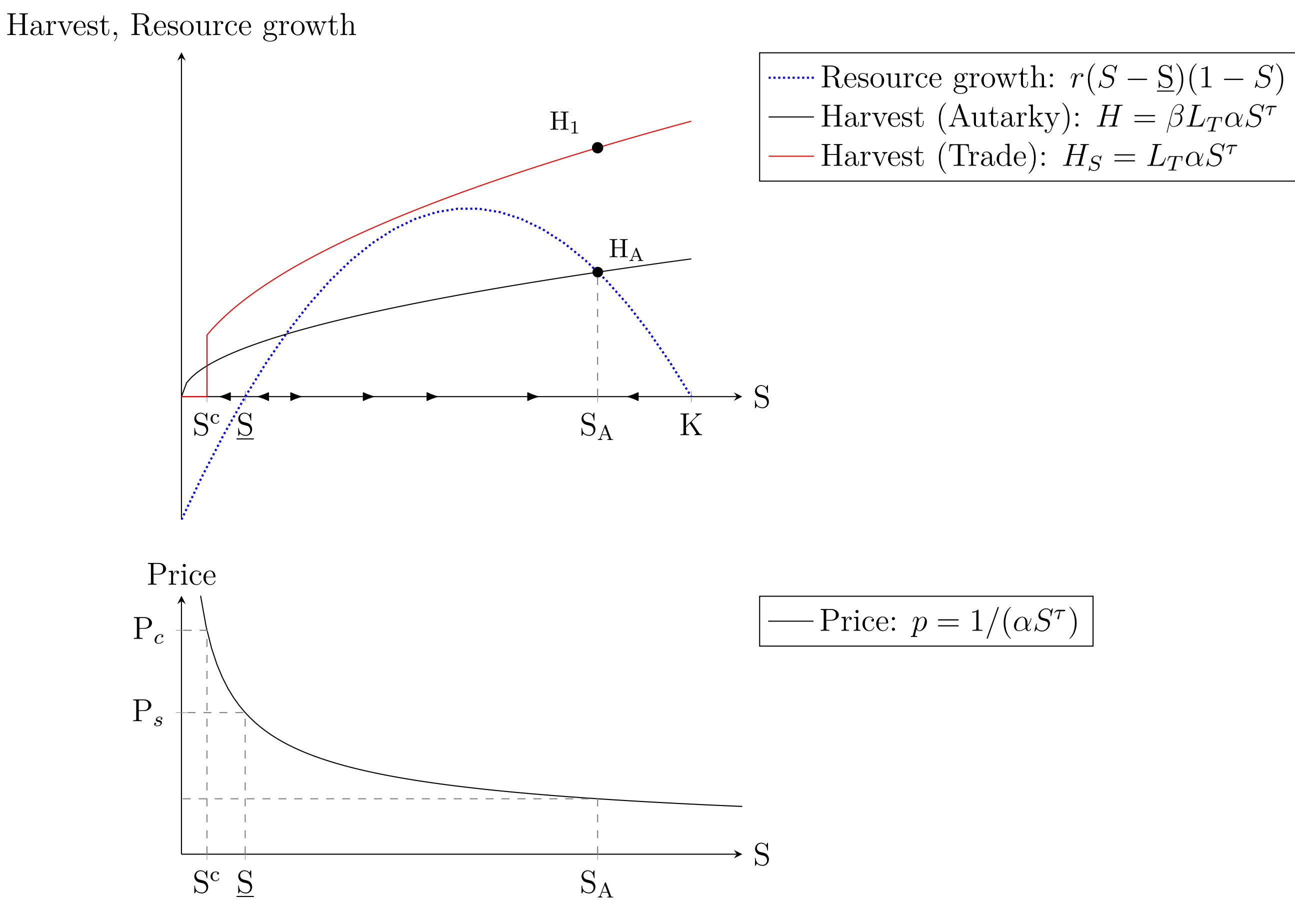
$$dS/dt = G(S(t)) - H(t). \tag{1}$$

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

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

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

Figure 1: Resource dynamics and catch function



The bottom panel of Figure 1 shows all price-resource stock combinations which yield a diversified pattern of production.

Fishing is characterized by the following function in which α describes the fishing technology and τ is a schooling parameter[3]

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

The term αS^{τ} in this equation captures fishing productivity. Each worker in the fishing industry catches more if technology α is more advanced or if the stock is larger. The extent to which the catch depends on the stock size is measured by τ. 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 and the wage rate w (see 10.2 in the Appendix)

$$p = \frac{w}{\alpha S^{\tau}}. \tag{4}$$

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.

Manufacturing production technology is given by $M = L_M$. The price of the manufacturing product is normalized to 1. Therefore, the wage rate in manufacturing equals 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.

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 10.1 in the Appendix shows that aggregate demand for fish, H^C, is

$$H^C = \frac{\beta w L_T}{p}. \tag{5}$$

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

2.2 Autarky equilibrium

In the short run autarky equilibrium, the supply of fish equals the demand for fish. Equations 4 and 5 pin down the short run supply of fish as a function of a given stock size

$$H = \alpha S^{\tau} \beta L_T. \tag{6}$$

This "short-run catch function" is depicted by the black line in Figure 1. Equation 6 shows that, in the short-run equilibrium, a fraction β of workers is employed in fishing.

In the autarky steady state equilibrium, catch equals the resource growth rate. Therefore, the autarky steady state is characterized by the intersection of the short-run catch function and the resource growth function.[4] 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.

The fishery can collapse in autarky if the parameters of the model change such that $G(S)$ and H do not intersect at any positive stock levels. In other words, there is no stable steady state if α, β, L_T and $\underline{S}$ are high or if r and K are very low. For certain parameter values, an increase in the preference for fish, reflected by a higher β, could lead to the collapse of the fishery even in the absence of trade.

2.3 Trade

This section investigates the effect of trade openness on a small country, for which the world market price is exogenous. The pattern of trade depends on the world market price p^* relative to the country's autarky price p_A. Since this paper analyses the effect of exports on the domestic fishery, trade is modelled as an exogenous increase in the resource price $p^* > p_A$.[5] The exposition below focuses on the case in which the country is in the autarky steady state when it first opens up to trade. However, the same results follow through when a small economy is in a diversified trading equilibrium and experiences an exogenous increase in the price. This exogenous increase in the price could result from a further trade liberalization or from an export demand shock.

[4] The steady state resource stock is the solution to $\beta L_T \alpha S^{\tau} = r\left[S - \underline{S}\right]\left[1 - \frac{S}{K}\right]$.

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

2.3.1 Short-term pattern of production and trade

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

Catch increases instantly when the country opens up to trade, since the country's entire labour force moves into the fishing industry. The instantaneous increase in catch is captured by a move from H_A to H_1 in Figure 1. H_1 is on the "specialized catch function" H_S

$$H_s = \alpha L_T S, \tag{7}$$

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

The country exports fish and imports manufacturing products when it opens up to trade. This is evident from the fact that the country only produces fish but workers consume both products.

The stock declines over time, since catch exceeds the resource growth rate once the country has specialized in fishing (e.g. at H_1). 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 10.3 in the Appendix.

2.3.2 Diversified steady state with a smaller stock

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

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

$$\frac{S_T}{S_A} = \left(\frac{\frac{1}{p^* \alpha}}{\frac{1}{p_A \alpha}}\right)^{\frac{1}{\tau}} = \left(\frac{p_A}{p^*}\right)^{\frac{1}{\tau}} < 1. \tag{8}$$

The steady state stock under trade is smaller than the autarky stock ($S_T < S_A$) if $p^*/p_A > 1$.[7] Equation 8 also shows that exporting is more detrimental to schooling fish species for which τ is small. These results can be summarized as hypotheses for the empirical analysis:

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

(a) an instantaneous increase in exports and

(b) a smaller resource stock in future periods.

(c) Stocks of schooling fish species shrink more, ceteris paribus.

2.3.3 Fisheries collapse as a result of trade

This section shows that a fishery, which is sustainable in autarky, can collapse when the country opens up to trade. Furthermore, it derives the conditions under which a collapse is possible.

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

Yet, a collapse can only occur if two conditions are satisfied: Firstly, a collapse can only happen if the world market price is high, i.e. $p_c \geq 1/(\alpha \underline{S}^\tau)$.[8] Secondly, a

[7] Equation 8 shows that stocks may recover in importing countries for which $p^*/p_A < 1$. If a country is not competitive on the world market because stocks in autarky are small and the autarky price is high, it can import fish and stocks can recover as long as they have not been depleted beyond $\underline{S}$. Brander and Taylor (1997*a*,*b*, 1998) discuss the way importing countries can benefit from trade in renewable resources.

[8] This implies that a collapse can only happen if the minimum viable stock size $\underline{S}$ is positive and fish population growth is negative for any stock $S < \underline{S}$. Negative population growth at small

collapse is only possible if harvest under specialization H_s exceeds resource growth $G(S)$ for any positive stock level.[9] This is the case if fishing capacity is high relative to the resource growth rate. Advanced fishing technology or a large labour force which can participate in fishing raise H_s and facilitate a collapse at high world market prices. A detailed analysis of the parameter values, for which a collapse is possible, is available in Section 10.4 in the Appendix.

The analysis above yields the following hypothesis for the empirical analysis:

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

2.4 Regulated fisheries

The model presented above looks at an unregulated open access fishery. If a regulator limits total allowable catch to Q through a quota, harvest can only increase to Q as a result of an exogenous increase in the price. As long as $Q < H_1$, this implies that harvest and exports in these regulated fisheries respond less to an exogenous increase in the price than in open access fisheries. Section 10.5 in the Appendix discusses this in more detail and shows that a fishery with a quota can only collapse if Q is extremely lenient and exceeds maximum sustainable yield (MSY). The following hypotheses will be investigated in the empirical analysis:

Hypothesis 3. *In regulated fisheries with stringent catch limits, (a) exports respond less to an exogenous increase in the price than in open access fisheries; (b) exports do not lead to the collapse of a fishery.*

stock levels is also called a "strong Allee effect". Slow recovery of depleted fish populations (Hutchings, 2000) suggests that Allee effects exist for some species and Keith and Hutchings (2012) find evidence for Allee effects for several species. However, even species which do not exhibit Allee effects can collapse as a result of trade, as demonstrated by Gars and Spiro (2018) in an Armington trade model.

[9] If this is not the case, the stock shrinks to the point at which catch under specialization equals resource growth (point S_z in Figure 4 in the Appendix). At this point, the stock cannot decline further since resource growth would exceed catch for any stock $S < S_z$ and the stock would recover. S_z is the specialized steady state discussed in Section 10.3 in the Appendix.

3 Empirical strategy

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. Due to the increase in exports and the resulting higher fishing pressure, the fishery can collapse in the exporting country. The empirical strategy ensures that trade is the only channel through which a collapse in Japan can affect the collapse of a fishery in another country.

3.1 Estimating equation

This paper estimates the effect of exports on the likelihood of a fishery's collapse. Even though this paper's identification strategy is based on the idea that an increase in the price (and hence in catch) leads to an increase in exports, I do not use price or catch data as regressors for two reasons. Firstly, the identification relies on a country being open to trade an exporting a particular species and this can only be guaranteed through the use of export data. Secondly, the majority of price data is estimated and hence of poorer quality than the export data.

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. Since stock assessments are only available for a small number of species, this paper uses a common approach (see e.g. Worm et al., 2006; Costello, Gaines and Lynham, 2008) and defines a fishery as collapsed if catch is below 10 percent of the maximum catch recorded since 1950. Based on finding by Froese et al. (2012), the variable Collapsed_{ikt} is unlikely to systematically misrepresent the depletion of fisheries, as Froese et al. (2012) show that trends in catch data are consistent with trends in biomass data from stock assessments.

In the dataset used for the analysis, fisheries are observed up to the year in which they collapse.[10] Once the fishery has collapsed, the stock is very low. This implies that catch 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.

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

$$\text{Collapsed}_{ikt} = \beta_0 + \beta_1 \ln(\text{Exports})_{ikt-1} + \boldsymbol{\beta}\text{Controls}_{ikt} + \gamma_{rt} + \gamma_i + \gamma_k + \epsilon_{ikt}. \quad (9)$$

An increase in exports will only manifest itself as a reduction in the fish stock 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 8.3 and 8.4.

In order to net out price effects, I use the export quantity rather than the export value as regressor. 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

[10]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.

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, Gaines and Lynham, 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 and capture time trends in fisheries collapse. 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. There is no need to use country-species fixed effects since there are no time-invariant country-species-specific factors which could be correlated with the instrument and violate the exclusion restrictions. 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, limited probability models require fewer functional form and distributional assumption and they offer a straightforward interpretation of the coefficient estimates as marginal effects. Finally, the estimated marginal effects from IV probit regressions with fewer fixed effects (either $\gamma_{rt} + \gamma_i$ or $\gamma_{rt} + \gamma_k$) were are almost identical to the marginal effects in a linear probability model. Considering the difficulties in implementing a non-linear model with a large number of fixed effects and instrumental variables, this paper only displays results from a limited probability model.

3.2 OLS estimates are biased downwards

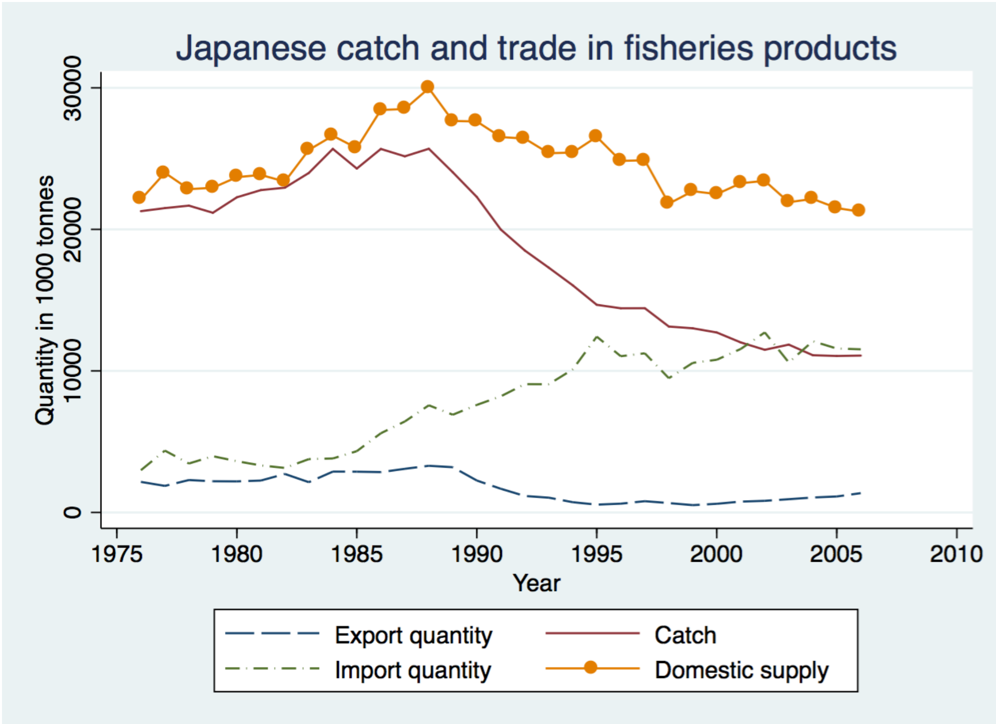
An OLS regression would underestimate the effect of exports on fisheries collapse. This holds true even if we only observe fisheries up to the point in which they collapse. The downward bias results from the fact that both exports in period $t-1$ and the dependent variable are correlated with the stock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

3.3 Collapse of Japanese fisheries as an instrument

To address this endogeneity, the collapse of Japanese fisheries is used as an instrument for fisheries exports in countries 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 both a large supplier and consumer of seafood. When Japanese catch declines as a result of the collapse, Japan sources more seafood products on foreign markets. The resulting increase in Japanese import demand raises the world market price 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.

Japan was the largest producer of fishery products until the late 1980s and caught around 18% of the world's marine catch at the beginning of the sample period in 1976. Japan's total supply of fishery products declined over the course of the sample period as Japanese fisheries collapsed. The percentage of collapsed fisheries in Japan increased from 14 percent in 1976 to 32 percent in 2006 and Figure 2 shows that total catch declined starkly during that time.

Figure 2: Japanese landings and trade in fishery products



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

An increase in imports guaranteed a stable supply of fishery products in Japan as domestic fisheries where depleted. The green dashed line in Figure 2 shows the rapid growth in fisheries imports, which made Japan the second largest importer of seafood products from 1987 onwards. Due to this increase in imports, the domestic supply (defined as production-exports+imports+stock changes) of fishery products remained relatively stable as demonstrated by the yellow connected line in Figure 2. Japan remains the second largest market for seafood products after China.[11]

Detailed price data corroborate the idea that the collapse of a Japanese fishery raises the price of the respective species in the rest of the world and thus lead to an export demand shock. Table 1 shows that a collapse in Japan is associated with an increase in the price of the affected species in the exporting countries by 7

[11]This paper does not use the collapse of Chinese fisheries as an instrument for exports, even though China has become the largest market for seafood products in the late 1980s, since Chinese landings statistics are likely to be overreported (see e.g. Pang and Pauly, 2001; Watson and Pauly, 2001; Pauly and Froese, 2012)

percent.[12] This increase in the world market price raises exports in the rest of the world and the first stage regression, which is discussed in Section 6.2, captures this effect. Since about two thirds of the price data are estimated, the remainder of the analysis focuses on export data to capture the effect of an exogenous increase in the price on the collapse of fisheries.

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

	(1)
Dependent variable	Ln (Price)$_{ikt}$
Collapse in Japan$_{it}$	0.075**
	(0.035)
Country FE, Species FE, Region-Year FE, Controls	Yes
Observations	8980.000

Standard errors (clustered at the species level) in parentheses. I control for the existence of a catch share program, country, species and region-year fixed effects. The sample covers the same observations as the baseline regression. * p<0.1, ** p<0.05, *** p<0.01

3.4 Exclusion restrictions satisfied

The instrument is only valid if trade is the only channel through which a Japanese collapse affects a collapse in the exporting country. In order to guarantee that the exclusion restrictions are satisfied, this paper only studies fisheries which are not shared between Japan and the exporting county. 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 (EEZ)[13] adjacent to Japan are excluded from the sample. The sample does not include Russia, North and South Korea, China, Taiwan, the Philippines and the Northern Mariana Islands.

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,

[12] Country-species-year level price data are from Swartz, Sumaila and Watson (2012), who collect a comprehensive dataset of ex-vessel prices and estimate missing price data. In the sample used for this paper, about two thirds of the price data are estimated. Therefore, the price data are not used for the remainder of the analysis.

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

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 Asssembly, 1982) as well as high sea fish species and all straddling fish stocks[14] 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 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.

4 Data

This section explains the construction of the novel country-species level dataset on trade in fishery products and 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).[15] The original dataset contains species-level information on catch for almost all countries in the world from 1950 to 2006.

Disaggregate fisheries trade data for the years 1976 to 2006 are from the FAO Fisheries Commodities Production and Trade Statistics. The trade data are matched with the catch data at the country-species-year level. The correspondence table which links catch and trade data at the country-species-level was constructed as part of this research project.

Two characteristics of the trade data are worth highlighting. Firstly, the dataset

[14]Straddling fish stocks are stocks which occur both within a country's Exclusive Economic Zone and beyond it.

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

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 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.

This paper uses data on catch share programs from the Environmental Defense Fund (EDF). I use information from government websites, scientific articles and I contacted the respective fisheries management authorities to complete missing information on the year in which a catch share program was adopted.

5 Summary statistics

The summary statistics reveal that an increase in fisheries exports coincides with an increasing prevalence of fisheries collapse in exporting countries.

Exports of fishery products grew by 265 percent over the sample period. The total export quantity of fishery products in the sample used for this study increased from 1.2 million tonnes in 1976 to 4.4 million tonnes in 2006 (see Figure 3).[16] The summary statistics in Table 2 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.

This export growth coincides with an increasing prevalence of fisheries collapse in exporting countries. The red connected line in Figure 3 shows that the percentage of collapsed fisheries increased from 7 percent in 1976 to 25 percent in 2006. Fisheries collapse throughout the sample period. The green line in Figure 3 indicates that between 2 and 8 percent of the fisheries collapse every year. The summary statistics

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

Table 2: Summary statistics

	(1) Mean	(2) Overall Sd.	(3) Between Sd.	(4) Within Sd.
Collapsed	0.047	0.211	0.154	0.190
Export quantity (lag)	10.152	38.864	24.211	22.668
Export quantity (lag, ln)	6.578	2.679	2.667	1.105
Catch share (lag)	0.103	0.304	0.207	0.190
Collapsed Japan (lag)	0.127	0.333	0.252	0.236
Tariff Japan (lag)	6.140	2.227	2.204	0.712
Observations	8980	8980	8980	8980

Between Sd: Standard deviation between country-species combinations

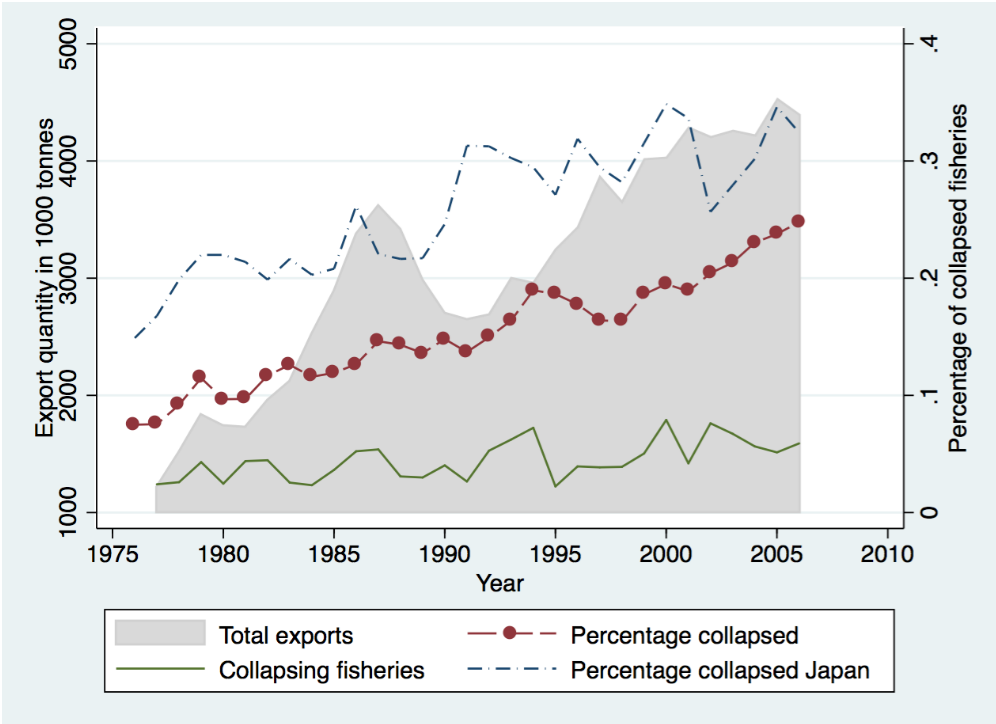
Within Sd: Standard deviation within country-species combinations

in Table 2 show that 4.6 percent of the observations represent collapsing fisheries, i.e. fisheries in the year of the collapse.

Most of the collapsed fisheries are cod, hake and haddock fisheries, as demonstrated by Table 11 in the Appendix. This holds true for both the exporting countries and fisheries in Japan.

Fisheries collapse is more prevalent in Japan than in the rest of the world. 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. Japanese stock assessment confirm the poor state of Japanese stocks. 43 out of the 90 assessed stocks within Japan's Exclusive Economic Zone were categorized as being at low levels in 2007 (Makino, 2010).

Figure 3: Fisheries collapse and export quantities in the sample



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

6 Results: Exporting leads to the collapse of fisheries

The results in this section show that exporting significantly raises the likelihood of fisheries collapse. The instrumental variable estimation addresses a downward bias in the OLS regression.

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 3 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 3.3, it may be due to a downward bias of the coefficient estimate. The result from the instrumental variable regression in

Table 3: OLS and baseline results

	(1) OLS	(2) 1st stage	(3) IV
Dependent variable:	Collapsed	Exports	Collapsed
Export quantity (lag, ln)	-0.004**		0.087**
	(0.002)		(0.037)
L.Col. Japan		0.258***	
		(0.083)	
L.Catch share	-0.012	0.483**	-0.055*
	(0.011)	(0.202)	(0.031)
Previously Collapsed	0.061***	-0.760***	0.131***
	(0.009)	(0.164)	(0.033)
Year Fixed Effects	Yes	Yes	Yes
Species Fixed Effects	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes
Intrumental Variable			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

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 3 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 test by Stock and Yogo (2005) confirms that the instrument is sufficiently strong.[17] Moreover, the Kleibergen-Paap first stage F-statistic[18] of 9.9 in the baseline model is just at Staiger and Stock (1997)'s threshold for sufficiently strong instruments of 10.

In addition to standard hypothesis tests, this paper reports weak instrument robust hypothesis tests for all regressions. The penultimate column of all results tables in this paper is labelled "Anderson-R. p-value" and shows the p-value for Anderson and Rubin (1949)'s test of structural parameters which is fully robust to weak instruments. When this p-value is below 0.1, the coefficient estimate for the export quantity is significant even when the instruments are weak. This is relevant for regressions in which the first-stage F-Statistics is below 10. In those regressions hypothesis tests and confidence intervals can be wrong when instruments are weak (see e.g. Stock, Wright and Yogo, 2002).

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. Any reader worrying about weak instruments should think of the coefficient estimates 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 3 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 points. The effect is large: An increase in logged exports by one standard deviation raises the likelihood of a collapse by 23 percentage points.

Are the estimates realistic in light of the observed trend in fisheries collapse over the sample period? An answer to this question requires more insights into the development of exports during the sample period. Exports in the median

[17] Based on this test, I can reject the null-hypothesis that the asymptotic bias of the 2SLS bias exceeds 15% of the OLS bias.

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

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 collapse. However, these numbers have to be interpreted with caution since they extrapolate an estimated short-term effect over a time period of 30 years.

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

7 Heterogeneous effects

This section presents heterogeneous effects and shows that they are in line with the theoretical hypotheses. The results suggest that exporting only leads to the collapse fisheries which are not regulated via catch share programs. Moreover, schooling fish species and fisheries with large fishing capacity are more likely to collapse due to exports. The possibility to harvest a species using aquaculture production seems to dampen the effect of exports on the collapse of fisheries.

7.1 Only fisheries without quotas are affected

This section shows that exports only raise the likelihood of a collapse in fisheries which are not regulated via quotas or similar rights-based management tools. Regulated fisheries do not seem to be affected by exports.

In order to test whether the effect of exports depends on fisheries management, 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.[19]

[19] Adding an interaction term between the export quantity and the catch share dummy variable would allow me to test for a difference between the two groups. However, such a test would require a second instrumental variable which I lack.

The empirical findings for fisheries which are regulated via catch share programs are in line with Hypothesis 3. The first stage regression reveals that a collapse in Japan does not lead to a significant increase in exports from catch share fisheries. Moreover, the results from the second-stage regression in Column 1 of Table 4 show that exports do not spur a collapse of fisheries which are regulated via catch share programs. However, the weak correlation between the instrument and exports in the sample of managed fisheries implies that the second-stage regression results may be biased downwards and have to be interpreted with caution.

The results indicate that only fisheries which are not managed via catch share programs collapse as a result of exports. Column 2 of Table 4 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. This sample includes fisheries which are not managed via catch share programs but adopt those programs later on. In a sample of fisheries which are never managed via catch share programs, an increase in exports by one percent raises the likelihood of a collapse by 0.97 percentage points (see Column 3).

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

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

	(1) Quota	(2) No quota	(3) Never managed
Export quantity (lag, ln)	-0.093	0.110**	0.097***
	(0.066)	(0.047)	(0.035)
Controls	Yes	Yes	Yes
Fixed effects $\gamma_{rt}, \gamma_i, \gamma_k$	Yes	Yes	Yes
1st stage F-Stat	1.915	8.923	10.133
Anderson-R. p-value	0.082	0.006	0.004
Observations	992.000	7985.000	6552.000

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

7.2 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 Hypothesis 1.c holds true in the data, I compare forage fish,[20] 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 4 shows that an increase in exports by one percent raises the likelihood of a collapse by 0.067 percentage points 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.

7.3 Countries seem to have the capacity to overfish

Section 2 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 confirms empirically that the effect of exports on the collapse of fish stocks is slightly higher in fisheries with a large fishing capacity.

Fishing capacity is proxied by 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 Hypothesis 2, 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 5 suggest that an 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 0.07 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.

[20] Forage fish are small pelagic fish in the middle of marine food webs, such as herrings, anchovies, and sardines. Fishing raises the likelihood of a collapse (see e.g. Beverton, 1990; 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 5: Heterogeneous effects: Shoaling species and fishing capacity

	(1) Not schooling	(2) Forage	(3) Many fishers	(4) Few fishers
Export quantity (lag, ln)	0.064**	0.240	0.097	0.067
	(0.029)	(0.189)	(0.063)	(0.060)
Fixed effects $\gamma_{rt}, \gamma_i, \gamma_k$	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
1st stage F-Stat	12.968	2.794	5.192	4.782
Anderson-R. p-value	0.027	0.066	0.080	0.111
Observations	5757.000	1024.000	4452.000	4454.000

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

It is possible that all countries have the capacity to fish in excess of resource growth at any positive stock level. Therefore, the hypothesis 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 could explain the finding that exporting leads to the collapse of fisheries even when the number of fishermen is small or the fish population growth rate is high (see Column 1 and 2 of Table 6).

Table 6: Heterogeneous effects: Growth rate and aquaculture

	(1) Low growth	(2) High Growth	(3) Aquaculture	(4) No Aqua.
Export quantity (lag, ln)	0.107	0.106	-0.080	0.087**
	(0.074)	(0.078)	(0.212)	(0.035)
Fixed effects $\gamma_{rt}, \gamma_i, \gamma_k$	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
1st stage F-Stat	2.878	1.486	1.640	9.877
Anderson-R. p-value	0.044	0.013	0.660	0.007
Observations	3465.000	3261.000	334.000	8644.000

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. Column 1 (2): Sample of fisheries with fish population growth rate as reported by Cheung and Sumaila (2015) below (above) the median. Column 3: Sample of fisheries for which the FAO (Fishstat J) reports positive aquaculture production. Column 4: No aquaculture production reported.

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

7.4 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 depleted due to exports. Column 4 of Table 6 reveals that the results from the baseline regression follow through if fisheries which report positive aquaculture production are excluded from the sample.

8 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 discuss potential alternative instruments and substitution across species. The end of this section sheds more light on the dynamic relationship between exporting and fisheries collapse.

Further robustness test are available in the empirical appendix in Section 11. Section 11.1 shows that the results are not biased due to measurement error in the dependent variable and that they follow through with different definitions of fisheries collapse. Section 11.2 dispels concerns about a potential downward bias in the coefficient estimate due to increased fishing pressure for species j as a result of a collapse of species i. Section 11.3 shows that the findings follows through if net exports are used as an alternative measure for trade openness.

8.1 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.

8.1.1 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 the exporting countries in the sample.

In practise, there are several reasons why this is not a concern. Firstly, Swartz et al. (2010) argue that higher operating cost as well as increasing cost of accessing foreign country's fishing grounds[21] lead to the decline of the Japanese long distance fleet. Currently, the Japanese fleet's 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 increases as a result of a collapse in Japan. Table 12 shows that a collapse of species i in Japan's Exclusive Economic Zone is not associated with an increase in the Japanese fleet's landings of species i outside of the FAO fishing area which surrounds Japan.

To corroborate the validity of the instrument, I show that the results 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 country k's borders.[22]

Controlling for the Japanese long distance fleet's landings does not change the results, as shown in Table 7. An increase in exports by 1 percent is estimated to raise the likelihood of a fishery's collapse in the following year by 0.083 percentage points. This is almost identical to the coefficient estimate in the baseline regression.

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

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

Table 7: No violation of instrument exogeneity

	(1) Jap. col.	(2) Timing	(3) Northeast	(4) West
Export quantity (lag, ln)	0.083**	0.088**	0.092***	0.087**
	(0.033)	(0.044)	(0.031)	(0.036)
L.Foreign fleet landings	-0.001***			
	(0.000)			
Fixed effects $\gamma_{rt}, \gamma_i, \gamma_k$	Yes	Yes	Yes	Yes
Controls	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

8.1.2 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 extend that its own fishery collapsed. This is unlikely to drive the results for several reasons. The main reason 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.

The results for a regression using this slightly smaller sample are presented in Column 2 of Table 7. 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.

8.1.3 Environmental factors do not violate instrument exogeneity

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 by 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)[23] are excluded from the sample.

The results are displayed in Columns 3 and 4 of Table 7, respectively. In both case an increase in exports by one percent is estimated to raise the likelihood of a collapse by around 0.09 percentage points. This is very similar to the coefficient estimate in the baseline regression, indicating that the results are not driven by

[23] A map of FAO fishing areas is available on http://www.fao.org/fishery/area/search/en.

biological or environmental spillovers between fisheries in Japan and exporting countries in the Northeast and Western Pacific.

8.2 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.

8.2.1 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 tariff[24] at the species level is a weak instrument for exports. Due to the low time variation, the Japanese imports tariff is not significantly related to exports in the first stage regression.

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 shorter sample period from 1988-2006.[25]

[24] The analysis is based on preferential tariff data 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".

[25] 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 regressions with with country fixed effects, species fixed effects and region-year fixed effects.

Table 8: Alternative instruments

	(1) IV tariff	(2) IV distance	(3) Spillovers
Export quantity (lag, ln)	0.030	0.076**	0.080**
	(0.041)	(0.035)	(0.034)
Fixed effects $\gamma_{rt}, \gamma_i, \gamma_k$	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

8.2.2 Exporter's distance from Japan

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

Exports are likely to react less a to the collapse of a Japanese fishery if a country is far away from Japan.[26] Therefore, the instrumental variable "Collapse Japan" is interacted with a measure for the distance between Japan and the exporting country. Distance is measured as the great circle distance (in 1000km) between the most important cities in terms of population in each country using data are 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 8, is only slightly smaller than the coefficient estimate in the baseline regression.

8.2.3 No evidence of substitution on the demand side

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.

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

Substitution effects may occur since the collapse of a Japanese fishery is associated with an increase in the price of the affected species. In response to this increase in the price, consumers may shift their expenditure to close substitutes. If import demand for closely related species increased, the coefficient estimate in the first stage regression would be biased downward.

Species from the same family are likely to be close substitutes since they share a lot of characteristics. Therefore, the variable "Col. J. Family$_{it}$" can be used as a second instrument to assess spillover effects. 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 on the demand side. 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 8 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. It is reassuring that the test for overidentifying restrictions suggests that the instruments are valid.

8.3 Dynamics

This section shows that the medium-term and long-term effect of exports on the likelihood of a fishery's collapse is slightly 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.

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 9 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 estimate is slightly higher than the short-term effect estimated in the baseline regression.[27]

The theoretical model in Section 2 predicts a temporary peak in catch and

[27] I 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 9). 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 an instrument for exports in period $t-l$.

exports as a result of the exogenous increase in the price. Even if the price stays high, exports decline over time as the stock declines. 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 9 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.

Table 9: 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. * $p<0.1$, ** $p<0.05$, *** $p<0.01$

8.4 Exporting reduces stock biomass

This section uses biomass data to capture both the short-run and long-run effects of exports on fish stocks. The theoretical model in Section 2 shows that the stock in any period is a function of the stock in the previous period, of resource growth and catch. 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 and confirm that exports can have a detrimental effect on fish stocks.

8.4.1 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 2, current stocks are a linear function of the natural logarithm of stocks in period $t-1$, $ln(S_{ik,t-1})$ and of the natural logarithm of the export quantity in period $t-1$, $ln(\text{Exports})_{ik,t-1}$.

This yields the estimating equation 10, 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 represented by the variable "Catch share$_{ikt-1}$".

$$ln(S_{ikt}) = \alpha_1 ln(S_{ikt-1}) + \alpha_2 ln(\text{Exports})_{ikt-1} + \alpha_3 \text{Catch share}_{ikt-1} + \gamma_t + \eta_{ik} + \epsilon_{ikt} \quad (10)$$

The short-term effect of exports on biomass is captured by the coefficient α_2 in Equation 10. Based on the theoretical model presented in Section 2 and hypothesis 1, an increase in exports in period $t-1$ is associated with a reduction in stock biomass in period t.

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

Equation 10 is estimated using an Arellano-Bond estimator. The Arellano-Bond model uses the first difference of Equation 10 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 11.4.

8.4.2 Results: Exporting reduces stock biomass

Table 10: 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. Standard errors for the long term effect are calculated using the delta method.
* 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.[28] The short-term effect is captured by the

[28] The usual specification tests suggest that the model is correctly specified. The Arellano-Bond test shows that the null-hypothesis of second-order serial autocorrelation in the first-differenced error term can be rejected. The p-value of the test is shown in the third but last row of the

coefficient estimate for the export quantity in the first column of Table 10. 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.

9 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 estimated effect is large but not unrealistic. The predicted increase in the likelihood of a collapse for the median fishery is equivalent to roughly two thirds of the observed increase in the percentage of collapsed fisheries over the sample period.

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

results table. Moreover, the p-value for the Hansen test, displayed in the penultimate row of Table 10, shows that the null-hypothesis of valid moment conditions cannot be rejected.

This paper focuses on the collapse of fisheries in exporting countries. An assessment of the overall effect of trade on fisheries is beyond the scope of this paper for two reasons. Firstly, this paper cannot identify the effect of fisheries imports on a stock's potential recovery in importing countries, since the collapse of Japanese fisheries is a weak instrument for imports.[29] Secondly, a stock's recovery in importing countries may be temporary. Copeland and Taylor (2006) show that, in the long run, trade could lead to the serial depletion of all fisheries. Future research of trade's overall effect on fisheries should take patterns of serial depletion into consideration.

[29] Imports seem to be very price-inelastic and the collapse of fisheries in Japan is not associated with a significant reduction in imports in the rest of the world.

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10 For online publication: Theoretical Appendix

10.1 Demand for fish

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

$$u = h^{\beta} m^{(1-\beta)}. \tag{11}$$

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

$$ph + m = w \tag{12}$$

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 (11) subject to the budget constraint (12) 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

$$H^C = hL_T = \frac{\beta w L_T}{p}. \tag{13}$$

10.2 Price of fish

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

$$\frac{w}{p} L_H = \alpha L_H S^{\tau}. \tag{14}$$

This equation can be solved for the open access resource price in Equation 4.

10.3 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.

The specialized steady state S_z is illustrated in Figure 4. 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. The price p_z is shown in the bottom panel of Figure 4.

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 $p^* > p_z > p_A$.[30] The economy instantly specializes in fishing and catch surges from H_A to H_1, as shown in the top panel of Figure 4. The stock shrinks gradually due to the intense fishing pressure. Once the stock has diminished to S_z, it cannot decline further. If the stock were to decline slightly more, resource growth would exceed catch and the stock would recover. Therefore, S_z is a stable steady state and the fishery cannot collapse even at high resource prices. The economy remains specialized at S_z, since the marginal value product of labour exceeds the marginal value product of manufacturing at $p^* > p_z$.

10.4 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

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

Manipulating terms yields

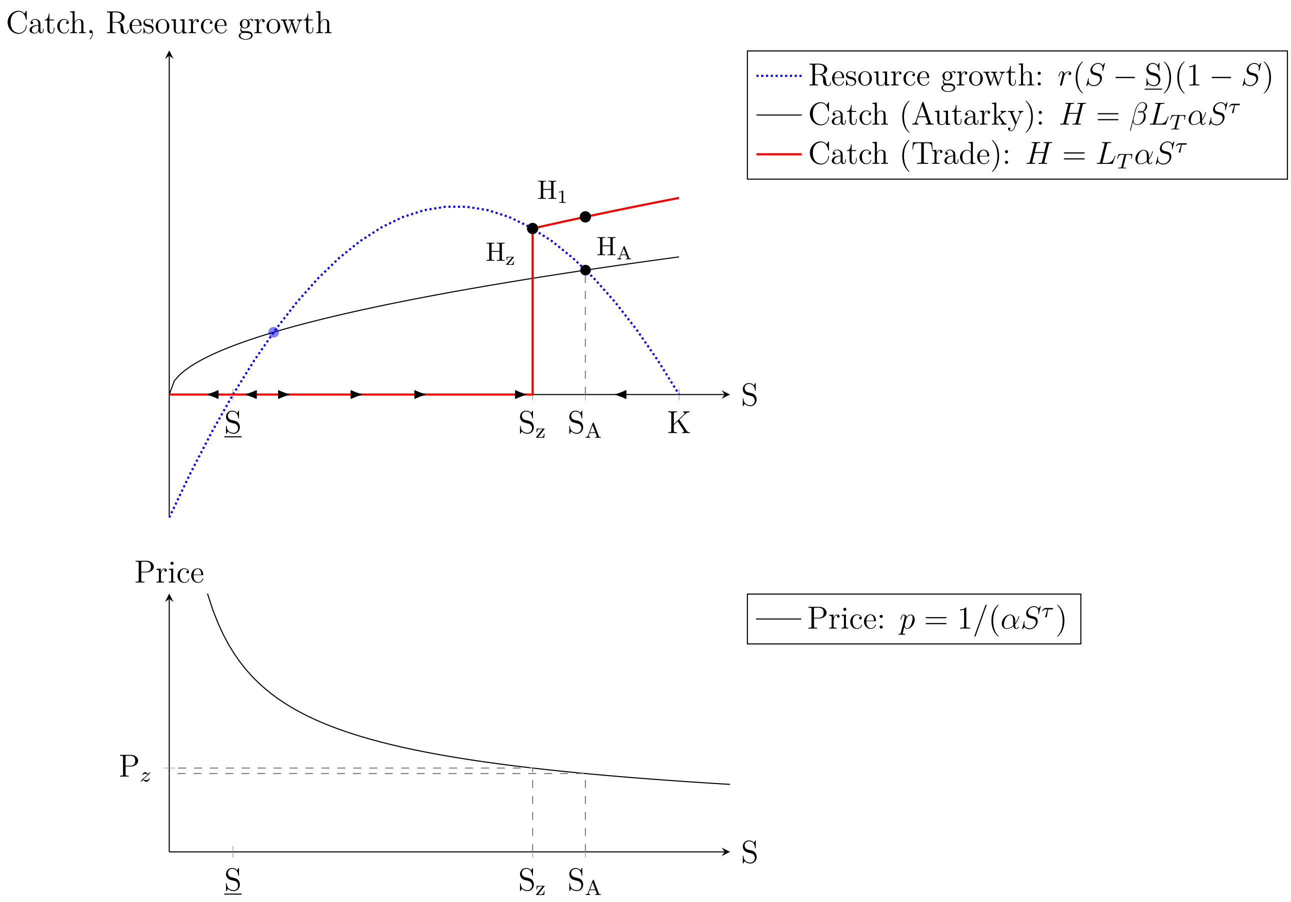
$$S^2 + (L_T \alpha K/r) S^{\tau} - KS + \underline{S}(K - S) > 0 \tag{16}$$

Condition (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) is more likely to hold if fishing pressure is high relative to resource

[30] 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 2.3.2.

Figure 4: Specialized steady state



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.

10.5 More on regulated fisheries

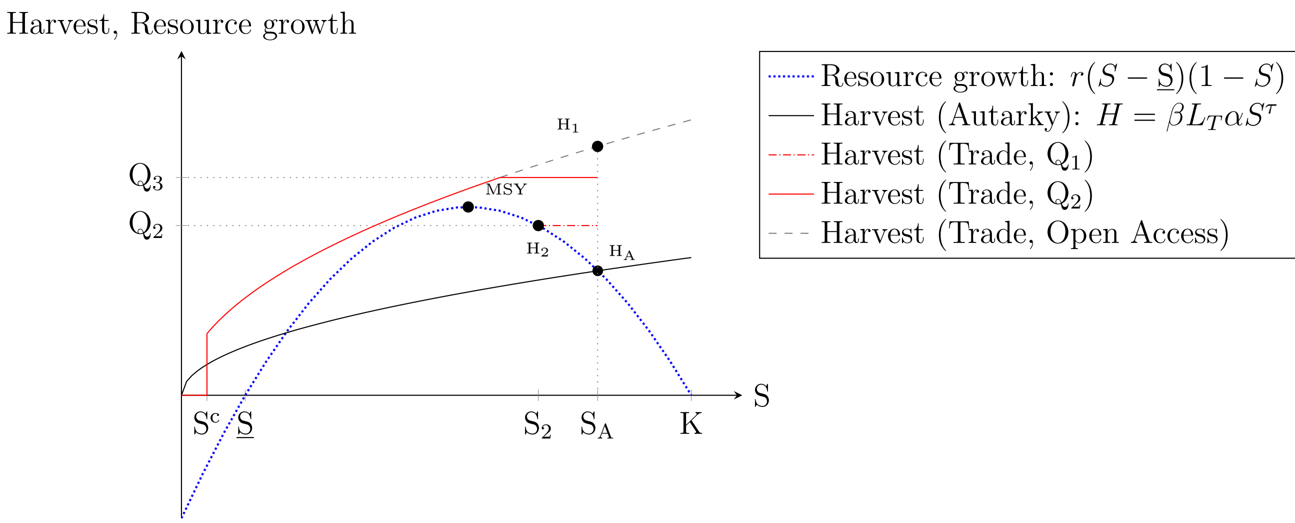
The effect of trade on regulated fisheries depends on quota Q which determines the maximum catch in the fishery. It is possible to distinguish between a scenario in which Q is binding in autarky and two scenaria in which it is not binding. The outcomes for non-binding quotas are shown in Figure 5.

1. If the quota is binding in autarky such that $Q_1 \leq H_A$, an exogenous increase in the price does not affect catch, exports or fish stocks.

2. If the quota is not binding in autarky and $H_A < Q_2 <$ MSY (maximum sustainable yield), harvest increases to Q_2 when the country opens up to trade and $p* > p_A$. As a result, the stock declines over time. At high world market prices $p* > p_2 = 1/(\alpha S_2^{\tau})$, the stock declines up to the point at which harvest under the quota equals resource growth. This point, denoted H_2 in Figure 5, represents a specialized steady state in which the economy only produces fish. If the world market price $p* < p_2$, the economy diversifies at a stock level S_T as described in Section 2.3.2. In either case, the instant increase in harvest or exports under a quota regime is smaller than under open access. The fishery does not collapse, even at high world market prices.

3. The quota is not binding in autarky and $Q_3 > MSY$. Upon opening up to trade, catch instantly increase to Q_3 and develops along the solid red function shown in Figure 5 as the stock declines over time. In that case a collapse is still possible under the same conditions as those mentioned in the previous section.

Figure 5: Resource dynamics and catch function with fishing quotas



11 Empirical Appendix

Table 11: Which fish species collapse?

	Exporting countries	Japan
Abalones, winkles, conchs	3	2
Cods, hakes, haddocks	111	32
Crabs, sea-spiders	1	3
Flounders, halibuts, soles	52	23
Herrings, sardines, anchovies	59	5
King crabs, squat-lobsters	11	0
Lobsters, spiny-rock lobsters	20	0
Miscellaneous coastal fishes	4	18
Miscellaneous demersal fishes	38	30
Miscellaneous diadromous fishes	4	0
Miscellaneous pelagic fishes	21	18
Oysters	6	0
Salmons, trouts, smelts	35	5
Scallops, pectens	8	0
Sea-urchins and other echinoderms	4	0
Sharks, rays, chimaeras	1	10
Shrimps, prawns	13	0
Squids, cuttlefishes, octopuses	28	15

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

Table 12: Long distance fleet landings do not increase

	(1) Foreign fleet landings
Col. Japan	-781.931
	(1075.277)
Species FE	Yes
Year FE	Yes
Observations	1318.000

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

11.1 No bias due to measurement error in fisheries collapse

Even though the collapse of fisheries is inferred based on catch statistics, measurement error in the dependent variable does not seem to affect the results. This section discusses two reasons why the collapse of fish stocks may be mis-measured: a reduction in the price of fish or the introduction of fisheries management could both lead to a drastic reduction in catch which does not represent a collapse of the fish stock. However, it is shown that neither of these factors bias the results. Moreover, the results are qualitatively similar if the threshold for a collapse is changed, as demonstrated in the last part of this section.

Let us denote the measurement error in fisheries collapse by $e_{ikt} = collapsed_{ikt} - collapsed^*_{ikt}$ where $collapsed^*$ is the true collapse of a fishery and $collapsed$ is the measure for a fishery's collapse which is inferred based on catch statistics and which is used in the analysis. With measurement error e_{ikt} in the dependent variable, the estimating equation is

$$\text{Collapsed}_{ikt} = \beta_0 + \beta_1 \ln(\text{Exports})_{ikt-1} + \boldsymbol{\beta}\text{Controls}_{ikt} + \gamma_{rt} + \gamma_i + \gamma_k + \epsilon_{ikt} + e_{ikt}. \quad (17)$$

The first concern is that measurement error leads to a violation of the exclusion restrictions if e_{ikt} is correlated with the instrument. This could be the case if a stark reduction in global demand for a particular species lead to a drop in the world market price and, as a result, fishermen in Japan and the exporting country would cease to catch the species. While this is a theoretical possibility, the author is not aware of any example of a global reduction in demand. Moreover, the empirical results in Table 1 show that the collapse in Japan is associated with an *increase* in the world market price. This finding is inconsistent with a reduction demand for the affected fish species.

Furthermore, there is no evidence that the results are biased due to a potential measurement error resulting from the introduction of fisheries management. It is possible that a fishery is falsely measured as collapsed when a government introduces particularly strict catch limits. However, this does not appear to be relevant in practise. There are only three fisheries in the sample for which the introduction of catch share programs coincides with the collapse of the fishery. Stock data, which are available for one of those fisheries, suggest that the stock had actually declined drastically. If the above-mentioned three fisheries are excluded

Table 13: Measurement error

	(1) Collapsed (10%)	(2) Collapsed (5%)	(3) Collapsed (15%)
Export quantity (lag, ln)	0.092**	0.053	0.089*
	(0.036)	(0.042)	(0.045)
Fixed effects $\gamma_{rt}, \gamma_i, \gamma_k$	Yes	Yes	Yes
Controls	Yes	Yes	Yes
1st stage F-Stat	9.759	8.780	12.776
Anderson-R. p-value	0.002	0.114	0.047
Observations	8941.000	9663.000	8461.000

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. Column 1: Fisheries for which the introduction of management coincides with the collapse are excluded from the sample. Columns 2 and 3: Sample only includes fisheries which have not collapsed according to the respective definitions of fisheries collapse.* p<0.1, ** p<0.05, *** p<0.01

from the sample, the results are similar to those from the baseline regression, as demonstrated in Table 13.

The results are also (partly) robust to changing the definition of fisheries collapse. This is shown for both stricter and more lenient definitions of fisheries collapse in Table 13. In Columns 2 (or 3) of the Table a fishery is defined as collapsed if catch is below 5% (or 15%) of the maximum catch recorded since 1950. Both columns suggest that exports raise the likelihood of a collapse, but the coefficient estimate is only statistically significant for the more lenient definition of fisheries collapse in Column 3.[31]

11.2 Substitution on the supply side does not drive results

This section argues that there is little concern of a downward bias in the coefficient estimates resulting from substitution on the supply side.

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

If there is substitution on the supply side, fishermen will catch more of species j in the years following a collapse of species i. The resulting increase in the likelihood of a collapse of species j would contaminate the control group and bias the coefficient estimates downward. In case of substitution on the supply side, the coefficient estimate for the export quantity would have to be interpreted as a lower bound.

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

Moreover, the results follow through if I control for different trends in the likelihood of a collapse resulting from substitution on the supply side. If fishermen target species j in response to a collapse of other species, fishing pressure for species j and the likelihood of a collapse of fishery jkt should increase in the percentage of collapsed fisheries within in country k at time t. Controlling for the percentage of collapsed fisheries captures different trends and removes any bias resulting from substitution on the supply side. Column 1 of Table 14 shows an increase in exports raises the likelihood of a collapse by 0.098 percentage point. The effect is only slightly higher than the coefficient estimate in the baseline regression.

11.3 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 of exports. The results in Column 2 of Table 14 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

Table 14: Substitution and net exports

	(1) Substitution	(2) Net exports	(3) Prev. net exp.
Export quantity (lag, ln)	0.098**		
	(0.039)		
Percentage collapsed	0.454***		
	(0.101)		
L.Ln(Net Exports)		0.157	
		(0.128)	
Ln(Max. Net Exp. up to t)			0.071*
			(0.042)
Region-Year FE	Yes	Yes	Yes
Species FE	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Controls	Yes	Yes	Yes
1st stage F-Stat	9.212	2.289	7.644
Anderson-R. p-value	0.002	0.014	0.039
Observations	8980.000	5880.000	9185.000

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

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). The p-value of the Anderson-Rubin (1949) test of 0.01 indicates that the coefficient estimate is statistically significant based on weak instrument robust inference.

The long-term effect of net exports on the collapse of a fishery can be captured by the maximum of a fishery's previous net exports. This regressor is motivated by the idea that an exogenous increase in the price 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. 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 3 of Table 14 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. 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.

11.4 Dynamic panel data model of stock biomass

Instrument matrix

When constructing the instrument matrix, the lag of stock biomass, exports and the catch share program are consider 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. Moreover, the introduction of catch share programs is treated as a predetermined variable and allowed to be a function of past biomass.

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).

Since the panel spans almost 30 years, a combination of both approaches is used 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),[32] who estimate stock biomass based on catch statistics.

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

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