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

Sabrina Eisenbarth[†]

This paper shows that exports are an important cause of resource depletion. The paper uses detailed country-species-level fisheries data to estimate the causal effect of a fishery's exports on the collapse of the fishery. Identification is based on an export demand shock originating from Japan. The results reveal that an increase in logged exports by one standard deviation raises the probability of a fishery's collapse in the following year by 31 percentage points. Particularly fisheries without catch share programs collapse when exports surge.

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

1 Introduction

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

This paper uses detailed fisheries data to estimate the causal effect of a fishery's exports on the collapse of the fishery. The paper employs a novel identification strategy, using an export demand shock originating from Japan as an instrument for exports in the rest of the world. The use of country-species-year level data on trade in fishery products yields detailed insights about the way exports affect the collapse of numerous different fish species. The results suggest that an increase in exports leads to a large increase in the probability of a collapse. When logged exports increase by one standard deviation, the probability of a collapse in the following year increases by 31 percentage points.

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

Insights on the effect of fisheries exports on fisheries collapse are especially important for developing countries, which produce more than half of global fisheries exports (FAO, 2016b). In the developing world, fisheries generate up to 50% of export revenue (Bellmann et al., 2016) as well as employment for more than 37 million people (FAO, 2016b). 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 (1997a,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 complete depletion of the resource stock.

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

The empirical analysis provides the first estimate of the causal effect of fisheries exports on the collapse of fisheries. This paper uses a standard definition of fisheries collapse (see e.g. Worm et al., 2006; Costello et al., 2008) and defines a species in a particular country as collapsed if catch within the country's Exclusive Economic Zone (EEZ) is below 10 percent of the maximum historical catch recorded since 1950. The use of a catch-based proxy for fisheries depletion is necessary since catch data are far more widely available than stock assessments. Scientific stock assessments are sparse and they mostly focus on high value and often well-managed stocks in the US, Canada, Australia, and New Zealand. Hence, assessed fisheries do not represent a random sample and an analysis based on assessed stocks cannot shed light on dynamics in major exporting fisheries in the developing world.

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

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

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

The paper shows that exports significantly contribute to the collapse of fisheries. The results suggest that an increase in exports by one percent raises the probability of a fishery's collapse in the following year by around 0.1 percentage points. This effect is large, particularly considering the surge in exports of fishery products in the last few decades. Exports in the median fishery grew by 52 percent between 1991 and 2006. According to the estimates, this export boom raised the probability of a collapse by 6 percentage points. A comparison with the rate of fisheries collapse in the sample helps to put this number into perspective. The rate of collapse was calculated for fisheries that report export data in 1991 and 2006 and are not collapsed in 1991. Twenty percent of these fisheries collapsed at least once between 1991 and 2006. Hence, median export growth predicts almost one third of the observed rate of collapse in this sample.

The use of price data allows for a more direct test of the theoretical model and confirms the insights gained from export data. The result suggest that an increase in the ex-vessel price raises exports and the probability of a collapse. However, those results are slightly more tentative since price data are mostly estimated and the collapse in Japan is a weak instrument for prices. Therefore, the analysis focuses on exports rather than prices as a regressor of interest.

Due to the sparsity of stock assessments, this paper infers the collapse of fisheries based on catch data. However, several authors have highlighted that the catch-based method measures the true depletion of fish stocks with error (Li and Smith, 2021; Carruthers et al., 2012; Branch et al., 2011; Daan et al., 2011). This is the case since catch is affected by a number of factors beyond biomass, such as input and output prices or fisheries management.

This paper takes several steps to ensure that measurement error in fisheries collapse does not drive the results. First, it uses the best available stock data and complements them with estimates of stock biomass from Costello et al. (2016). The insights point in the same direction with this alternative dataset. Second, the results are largely robust to changing the definition of fisheries collapse such that the threshold for a collapse is either less than or more than 10 percent of maximum historical catch.

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

Second, this paper provides better estimates of the effect of resource exports on resource depletion since it uses relevant information on resource trade flows at a very disaggregated level. To be precise, the analysis is based on species level fisheries exports, whereas existing papers use country level exports plus imports relative to GDP (see e.g. Ferreira, 2004; Faria and Almeida, 2016; Erhardt, 2018) or the implementation of regional trade agreements (Abman and Lundberg, 2020) as measures for trade openness. The use of species-level resource trade flows allows for a crucial distinction between effects of resource exports and imports. A country can export some fish species and import other fish species. Trade openness would protect the stocks of imported species[1] (Brander and Taylor, 1997a,b) and deplete

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

stocks of exported species. This important distinction is lost in existing analyses using aggregate country-level datasets.

Finally, this paper analyses the effect of fisheries exports on the depletion of a broad set of fisheries, whereas most of the existing literature focuses on other resources. To date, Erhardt and Weder (2015) and Erhardt (2018) provide the only empirical analyses of the relationship between trade openness and overfishing. However, neither of those papers can quantify the effect of fisheries exports on the depletion of fisheries due to a lack of fisheries trade data.[2] Based on both detailed and comprehensive fisheries trade data and a novel instrumental variable, this paper can, for the first time, estimate the causal effect of exports from a particular fishery on the collapse of that fishery.

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

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

This section uses a simple Ricardian trade model like Brander and Taylor (1997a) and Copeland and Taylor (2006) to illustrate under which circumstances exporting can lead to the collapse of a fishery. The discussion focuses on a situation in which the price of fish increases exogenously. As a result of this increase in the price, fishing becomes more lucrative and the country instantly catches and exports more fish. Due to this additional fishing pressure, the catch of fish exceeds resource

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

growth and the stock declines over time. At high world market prices, a fishery can collapse if fishing capacity is high relative to the resource growth rate.

This section provides an intuitive explanation of the way exports affect the fishery. Additional details are deferred to Section A in the Appendix.

2.1 Model setup

The small open economy analysed here consists of two industries: Fishing and manufacturing. The total labour supply is L_T. L_H workers are employed in the fishing industry,[3] and the manufacturing industry employs L_M workers. Labour is assumed to be mobile across industries.

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 1.

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

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

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

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

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 $S < \underline{S}$, resource growth is negative and the stock does not replenish naturally.[4]

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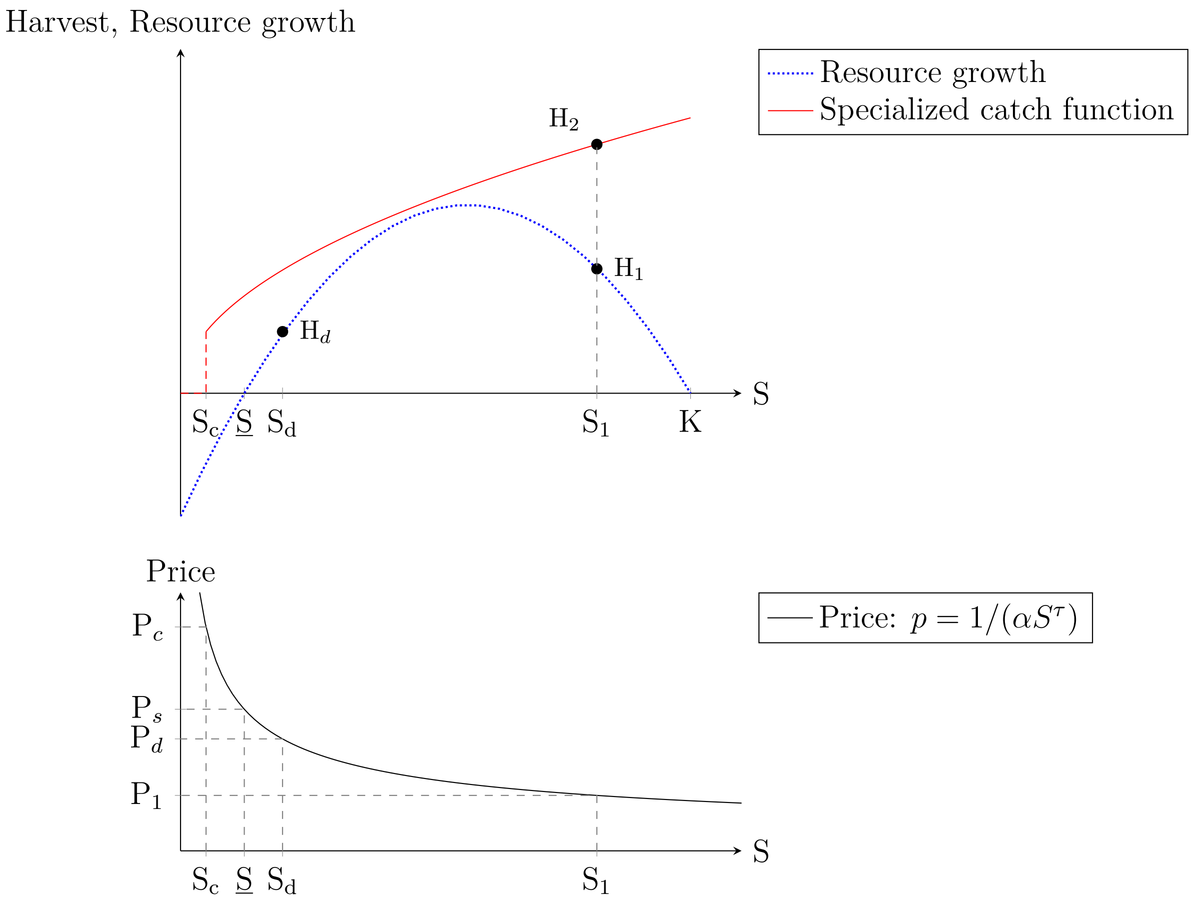
[3] The notation follows Brander and Taylor (1997a), where H represents harvesting of renewable resources.

[4] Negative population growth at small stock levels is called "critical depensation". Empirical

Figure 1: Resource dynamics and catch function



The top panel of Figure 1 plots the resource growth function and the specialized catch function. S$_1$ and H_1 represent the resource stock and harvest in the initial diversified steady state, respectively. H_2 is harvest under specialization given a resource stock of S_1. The graph in the bottom panel of Figure 1 shows all price-resource stock combinations that are compatible with a diversified pattern of production. The country specializes in fishing for any price and resource stock combination to the top right of this graph. A world market price of $p > p_s$ (e.g. p_c) would lead to a complete and irreversible depletion of the fish stock. A world market price of $p_d < p_s$ would lead to a smaller resource stock of S_d and a steady state harvest of H_d.

Fishing is characterized by the following catch function in which $\alpha > 0$ describes

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insights on depensation are hampered by data scarcity at low population levels (Hutchings, 2015; Winter et al., 2020). Keith and Hutchings (2012) document depensation for a subset of species. Some depleted fish stocks experience little or no recovery despite reductions in fishing pressure (Hutchings, 2000, 2015). This is suggestive of non-critical or critical depensation, respectively.

the fishing technology.

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

The term αS^{τ} in this equation captures fishing productivity. Each worker in the fishing industry catches more if technology is more advanced (and α is higher) or if the stock is larger. The extent to which the catch depends on the stock size is measured by the schooling parameter $\tau \leq 1$. Schooling fish species are relatively easy to catch even if the stock is small. When a species forms schools, τ is low and fishing productivity is not very responsive to the stock size.

The fishery is assumed to be an open access fishery. Workers can enter the fishing industry at any time t without restrictions or costs. As a result, profits from fishing are zero and revenue equals fishing costs. This implies $pH = wL_H$, where w is the wage rate in fishing. Substituting the catch function (Equation 3) into this zero-profit condition shows that the wage rate in fishing is equal to the marginal value product of labour in fishing.

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

If the $w = 1$, workers are indifferent between working in manufacturing and fishing and the country produces both goods. If the marginal value product of labour in fishing exceeds 1, the country specializes in fishing. The relationship between the resource stock and the resource price for a diversified economy is shown by the graph in the bottom panel of Figure 1. All price and resource stock combinations to the top right of the graph imply specialization in fishing.

The fishery operates in a small open economy. Therefore, the domestic price p is exogenous and equal to the world market price. The initial world market price for fish is denoted by p_1.

The economy is assumed to be in a diversified steady state equilibrium initially.[5] In this equilibrium, the wage rate in both industries equals 1 and the country produces both fish and manufactured goods. The initial steady state resource stock is determined by the world market price and given by $S_1 = \frac{1}{\alpha p_1}^{\frac{1}{\tau}}$.

In the diversified steady state equilibrium, harvest equals resource growth, i.e.

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[5] Depending on p_1 and the parameters of the model, the small open economy could either be in a diversified steady state, in a specialized steady state (described in Section A.2 in the Appendix) or the fishery could be completely depleted (discussed in Section 2.2.2). In the latter two steady states, an exogenous increase in the world market price would not affect catch, exports or stocks.

$H = G(S)$. Therefore, the blue dashed line in Figure 1 does not only represent resource growth. In the upper-right quadrant, it also represents harvest in the diversified steady state. The initial steady state harvest of $H_1 = G(S_1)$ is depicted on the blue dashed line in Figure 1. The proportion of the labour force employed in the fishing industry, $0 \leq \gamma \leq 1$, adjusts endogenously such that harvest equals resource growth and $\alpha S_1^{\tau} \gamma L_T = G(S_1)$.[6]

S_1 is a stable steady state resource stock. If more than γ workers moved into the fishing industry, the stock would decline and the marginal product of labour would fall. In that case, the marginal value product of labour would be higher in manufacturing. Workers would move into the manufacturing sector until the stock recovered to S_1. If workers moved out of fishing into manufacturing, the stock would grow, raising the marginal value product of fishing and attracting more workers into fishing.

2.2 Exogenous increase in the price

This section investigates the effect of an exogenous increase in the resource price resulting from an export demand shock in the rest of the world. The price is assumed to increase to $p_2 > p_1$. Since this paper analyses the effect of exports on the domestic fishery, the discussion focuses on parameter values of p_2 that are associated with fisheries exports. This is the case if p_2 is higher than the autarky price p_A.[7]

Insights presented in this section hold irrespective of the initial price p_1, as long as p_1 is compatible with a diversified steady state. If p_1 is equal to the autarky price, the outcomes described below are equivalent to an opening up to trade from autarky with a world market price of $p_2 > p_A = p_1$.

2.2.1 Short-term pattern of production and trade

As a result of the exogenous increase in the resource price the country specializes in fishing. Catch and exports increase instantly and the stock declines over time.

When the price increases, the country's entire labour force moves into fishing, since the marginal value product of labour in fishing exceeds the marginal value

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[6] The labour force is assumed to be sufficiently large to satisfy this.

[7] The autarky equilibrium is shown and discussed in Section A.1. If the $p_2 < p_A$, the economy would import fish.

product of labour in manufacturing, i.e. $\alpha S_1^\tau p_2 > \alpha S_1^\tau p_1 = 1$.

As a result, catch increases from $H_1 = \alpha\gamma L_T S_1^\tau$ to $H_2 = \alpha L_T S_1^\tau$. This is captured by a move from H_1 to H_2 in Figure 1. H_2 is on the "specialized catch function" H_S

$$H_S = \alpha S^\tau L_T, \tag{5}$$

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

Exports increase by the same amount as harvest since consumption of fish is unaffected by the change in the resource price.[8] The stock declines over time, since catch exceeds the resource growth rate once the country has specialized in fishing. This yields the first hypothesis for the empirical analysis, which also follows from Brander and Taylor (1997a)'s model.

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

(a) an instantaneous increase in catch and exports and

(b) a smaller resource stock in future periods.

Throughout the main body of the paper, it is assumed that catch under specialization exceeds resource growth for any stock $S > 0$.[9] This is the case if fishing technology is advanced and/or the labour force is large, such that fishing capacity is high relative to the resource growth rate.

Two steady state equilibria are possible if catch under specialization exceeds resource growth. High resource prices lead to the complete and irreversible depletion of the fish stock (S=0). Intermediate resource prices lead to a diversified steady state with a smaller resource stock. Both steady state equilibria are discussed below. A third, specialized steady state is possible if the specialized catch function and the resource growth function intersect. The specialized steady state is discussed in Section A.2 in the Appendix.

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[8] The demand side of the economy is discussed in Appendix Section A.1. With Cobb-Douglas preferences and open access to the resource, demand for fish is given by Equation 12 and does not depend on the price. Since both products are consumed, a country that specializes in fishing must export fish and import manufacturing products.

[9] This implies that the specialized catch function and the blue dashed resource growth function in Figure 1 do not intersect and that $L_T \alpha S^\tau > r\left[S - \underline{S}\right]\left[1 - \frac{S}{K}\right] \forall S \geq 0$.

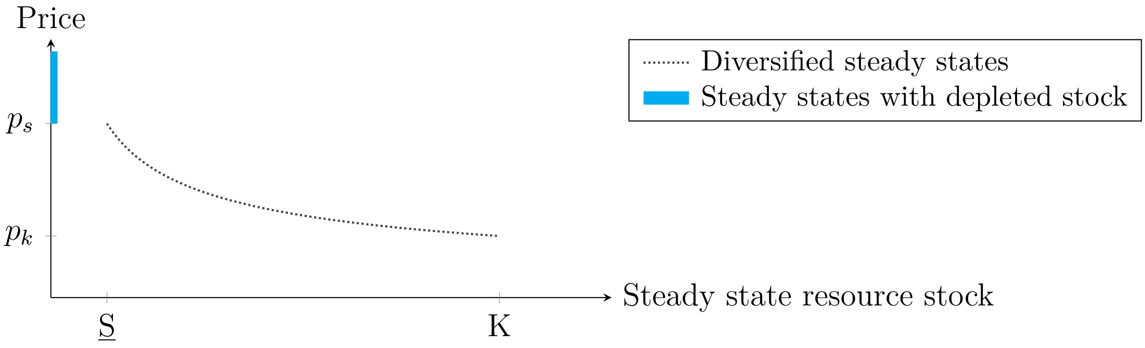
2.2.2 Complete depletion of the fish stock in the exporting country

This section shows that a fish stock can be completely and irreversibly depleted (S=0) in the steady state when the world market price for fish is high.

A possible catch function associated with complete depletion is illustrated by the red line in Figure 1. Given the world market price $p_c > p_1$, 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 labour in fishing equals the marginal value product of labour in manufacturing. At this point, workers could move out of fishing into manufacturing. However, even if this reduces catch and takes pressure off the resource, S_c cannot be a steady state resource stock. Resource growth is negative at S_c and the stock continues to decline to zero. The stock cannot recover once $S < \underline{\mathrm{S}}$. Hence, the stock is irreversibly depleted in the steady state.

All prices $p > p_s = 1/(\alpha\underline{\mathrm{S}}^{\tau})$ lead to irreversible depletion of the stock in the steady state. The blue line in Figure 2 illustrates this.

Figure 2: Relationship between the resource price and the steady state resource stock



This figure illustrates the relationship between the exogenous resource price and the steady state resource stock. The steady state stock is zero and the fishery is irreversibly depleted if $p > p_s$. The thick blue line overlapping with the y-axis shows steady states with depleted fish stocks. If $p_s > p > p_k$ (where $p_k = 1/(\alpha K^{\tau})$), the economy produces both goods in a diversified steady state. The grey dashed line shows all price and resource stock combinations corresponding to diversified steady states.

2.2.3 Diversified steady state with a smaller stock

A second potential outcome of an exogenous increase in the resource price is a diversified steady state with a smaller resource stock. A diversified steady state can occur if the resource price increases from p_1 to $p_2 = p_d$ but $p_d < p_s$. In the diversified steady state equilibrium, the stock has declined to S_d such that the marginal value product of workers in both industries equalizes and $p_d \alpha S_d^\tau = 1$. Solving this equation for S_d shows that an exogenous increase in the price leads to an unambiguous reduction in the steady state resource stock compared to the initial steady state stock.

$$\frac{S_d}{S_1} = \left(\frac{\frac{1}{p_d \alpha}}{\frac{1}{p_1 \alpha}}\right)^{\frac{1}{\tau}} = \left(\frac{p_1}{p_d}\right)^{\frac{1}{\tau}} < 1 \tag{6}$$

The steady state stock with the higher resource price is smaller than the initial steady state stock ($S_d < S_1$) if $p_d/p_1 > 1$.

Figure 2 also illustrates that a higher price leads to a lower steady state resource stock. The grey dashed line in Figure 2 shows all price and resource stock combinations associated with diversified steady states.

2.3 Relationship between the empirical definition of fisheries collapse and the theoretical insights on stock depletion

For the purpose of the empirical analysis, a fishery is defined as collapsed if catch is less than 10 percent of the maximum historical catch recorded since 1950. This empirical definition of collapse maps to two different types of steady state equilibria: either a complete depletion or a diversified steady state with a very small resource stock. A fishery can also be defined as collapsed during the transition period if harvest under specialization is less than 10 percent of maximum historical harvest.

First, the empirical definition of collapse maps to the steady state equilibrium with an irreversibly depleted stock (S=0). Stock depletion is only possible if the world market price p is higher than p_s, if the specialized catch function and the resource growth function do not intersect at positive stock levels and if resource growth is negative for a small stock $S < \underline{S}$.[10] If these conditions are satisfied,

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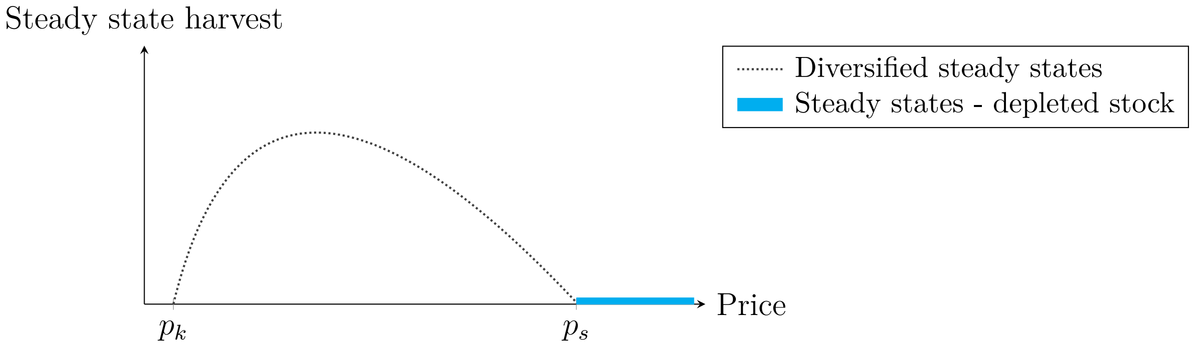
[10] Fisheries can be completely depleted as a result of trade in a model without a minimum viable stock size, as demonstrated by Gars and Spiro (2018) in an Armington trade model.

steady state harvest is zero, as illustrated by the thick blue line in Figure 3. Steady state harvest also equals zero along the transition to the depleted steady state: If the world market price is p_c, all workers move into manufacturing once the stock has been depleted to $S < S_c$. As a result, harvest is zero.

Figure 3: Relationship between the resource price and steady state harvest



This figure illustrates the relationship between the exogenous resource price and steady state harvest. The steady state stock and harvest are zero if $p > p_s$. This is represented by the thick blue line overlapping with the x-axis. The economy produces both goods in a diversified steady state if $p_s > p > p_k$. The grey dashed line shows all price and steady state harvest combinations corresponding to diversified steady states.

Second, an empirical collapse maps to a diversified steady state with a very small resource stock S_d. A diversified steady state is associated with an "empirical collapse" if the following conditions are satisfied. First, the price p_d is lower than the price p_s that would lead to complete depletion (i.e. $p_d < p_s$). However, the price has to be sufficiently high to ensure that harvest in the steady state is less than 10 percent of maximum historical harvest.[11]

Second, the specialized catch function does not intersect with the resource growth function. A diversified steady state with a very low resource stock does *not* require negative resource growth for small stocks. It would also be possible in a model with a standard logistic growth function of the form $G(S) = rS\left(1 - \frac{S}{K}\right)$.

In the diversified steady state equilibrium, harvest is positive and equal to resource growth at S_d. Since resource growth is positive at $S_d > \underline{S}$, the stock can

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[11] Harvest in the diversified steady state is equal to resource growth, i.e. $H = G(S)$. The relationship between the price and harvest in the diversified steady state is obtained by substituting $S = (1/p\alpha)^{\frac{1}{\tau}}$ into the resource growth function $G(S)$ from Equation 2.

recover if fishing pressure is reduced, e.g. as a result of a drop in the resource price or a temporary closure of the fishery.

Finally, a fishery can be defined as collapsed based on the empirical metric if it is still transitioning to the steady state equilibrium and harvest under specialization is less than 10 percent of maximum historical harvest.

When the fishery is collapsed, the resource stock is either equal to zero or very small and harvest is less than 10 percent of maximum historical harvest.

Insights from this section lead to the paper's main hypothesis:

Hypothesis 2. *An exogenous increase in the resource price and the associated increase in exports can cause the collapse of a fishery.*

A higher resource price can cause the collapse of fisheries since it leads to a surge in catch and exports. Therefore, Hypothesis 2 implies that an increase in exports can cause the collapse of fisheries. The empirical analysis tests this and analyses the effect of exports on the probability of a collapse.

3 Empirical strategy

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

To address this endogeneity, the collapse of fisheries within Japan's EEZ is used as an instrument for fisheries exports in countries that do not share fish stocks with Japan. The collapse of a Japanese fishery is associated with a significant reduction in Japanese catch. Since Japan is a large market for fishery products, the Japanese collapse raises the 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's waters. The empirical strategy ensures that trade is the only channel through which a collapse in Japan's EEZ can affect the collapse of a fishery in another country.

The empirical analysis focuses on the relationship between exports and fisheries collapse, even though the use of price data would allow for a more direct test of the hypotheses developed in Section 2. The paper does present results using price data, but those results will play a minor role since the collapse in Japan is a weak instrument for the price.

3.1 Estimating equation

This paper estimates the effect of exports on the probability of a fishery's collapse. The dependent variable Collapsed_{ikt} is a dummy variable that takes the value of 1 if fish species i has collapsed in country k's EEZ in year t. This paper uses a common approach (see e.g. Worm et al., 2006; Costello et al., 2008) and defines a fishery as collapsed if catch is below 10 percent of the maximum historical catch recorded since 1950. The catch data used to infer a collapse are from the Sea Around Us Catch Database (Pauly et al., 2020) and only include wild-capture fisheries. The catch database maps catch to a country's EEZ, irrespective of the flag of the fishing vessel that caught the fish. Hence, a collapse of a fishery means that catch within that country's EEZ has declined drastically compared to the historical maximum.

The collapse of fisheries has to be inferred from catch data since scientific stock assessments are sparse and do not cover a representative sample. The RAM Legacy stock assessment database covers a time series of 305 national stock assessments. Since trade data at the species level are not available for all species, less than 50 of these assessed stocks can be matched with trade data at the country-species level. Moreover, assessed fish stocks are not representative (Froese et al., 2012), since assessments are mostly conducted on high value, resilient and often well-managed stocks in the US, Canada, Australia, and New Zealand. An analysis relying on assessed stocks would not be able to capture the effect of trade on fisheries in developing countries, which are major exporters of fishery products (FAO, 2016b).

The variable Collapsed_{ikt} is unlikely to systematically misrepresent the depletion of fish stocks. Froese et al. (2012) have shown that trends in catch data are consistent with trends in biomass data from stock assessments. However, previous work has highlighted that that the catch-based definition of collapse measures the true collapse of fish stocks with error (Li and Smith, 2021; Carruthers et al., 2012;

Branch et al., 2011; Daan et al., 2011).[12] In light of this potential measurement error, this paper conducts a range of robustness checks - some using data from stock assessments in combination with estimates of biomass. All robustness tests suggest that the findings are not driven by a mismeasurement of fisheries collapse (see Sections 6.2 and Section C.3 in the Appendix).

In the dataset used for the analysis, fisheries are observed up to the year in which they collapse. Once the fishery has collapsed, the stock is very small. Hence the catch in subsequent years is very small, and it follows therefore that exports are low as well. In this case, the direction of causality runs from a collapse of a fishery, through low catches, to minimal exports. As a result, observations from collapsed fisheries cannot be used to understand whether exports lead to collapse. Therefore, observations from collapsed fisheries are excluded from the analysis sample after the year of the collapse.[13] Since fisheries are only in the analysis sample up to the year in which they collapse, the collapsed dummy variable takes a value of 1 in the year in which a fishery transitions into a collapse.

It is possible for a collapsed fishery to recover, and such fisheries reappear in the dataset once catch recovers to more than 10% of the historical maximum. 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.[14] Fisheries that do not collapse are observed until the end of the sample period in 2006.

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

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[12] Li and Smith (2021), e.g., use numerical simulations of bioeconomic models to evaluate the performance of the catch-based definition of collapse and show that the definition can generate false positives and false negatives. In other words, a fishery may be falsely defined as collapsed even though the stock is above 10% of the unfished stock and vice versa.

[13] Section C.9 shows that the collapse in Japan has a weaker effect on exports when collapsed fisheries are included in the sample. Furthermore, the estimated effect of exports on the probability of collapse is even higher than in the baseline regression when collapsed fisheries are in the sample.

[14] Section C.8 discusses results from a specification that also includes an interaction term between exports and the previous collapse of the fishery.

The analysis is based on the following estimating equation

$$\text{Collapsed}_{ikt} = \beta_0 + \beta_1 \ln(\text{Exports})_{ikt-1} + \beta_2 \text{Prev. Collapsed}_{ikt} + \gamma_{rt} + \gamma_i + \gamma_k + \epsilon_{ikt}. \tag{7}$$

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

This paper uses the natural logarithm of export quantities as regressor since the variable is highly skewed (see Section C.5 in the Appendix). Moreover, the use of logs simplifies the interpretation of the results. When exports are logged, the coefficient estimate $\hat{\beta}_1$ shows the estimated increase in the probability of a collapse in response to an increase in exports by 1 percent. Focusing on percentage changes in exports facilitates comparison across fisheries of different size.

Region-specific variation in climatic and environmental factors is captured by region-year fixed effects. Those fixed effects control for all factors that raise the probability of a collapse equally for all species in one region in a particular year and capture time trends in the rate at which fisheries collapse. A region is defined as either the Atlantic Ocean including the Mediterranean Sea or the Pacific Ocean and Indian Ocean. Results follow through if the region is defined at a smaller spatial scale as one of 19 FAO fishing areas (see Appendix Table 17).

Species fixed effects capture all time-invariant species characteristics that could affect the probability of a collapse. Those characteristics include the species' average rate of reproduction and the species' growth rate. Country fixed effects control for time-invariant country characteristics, such as the preference for fish. The results follow through with country-species fixed effects as demonstrated in Appendix Table 17.

Since the dependent variable is binary, this paper estimates a linear probability model as advocated by Angrist and Pischke (2008). There are several reasons to choose a linear probability model over a nonlinear binary dependent variable model such as logit or probit. First, Angrist and Pischke (2008) point out that 2SLS models estimate average local treatment effects even if the dependent variable is binary. Second, linear probability models require fewer distributional assumptions, particularly in the context of instrumental variable estimation (Cameron and Trivedi, 2010, ch. 14.8). Third, linear probability models 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 $\gamma_{rt} + \gamma_k$) are almost identical to the marginal effects in a linear probability model. Considering the difficulties in implementing a non-linear model with a large number of fixed effects and instrumental variables, this paper only displays results from a linear probability model.

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

The identification strategy assumes that there are no substitution effects across species. Substitution effects may occur since the collapse of a Japanese fishery is associated with an increase in the price. This could raise (export) demand for substitute species, making a collapse of substitutes more likely. In the case of substitution across species, the coefficient estimate of β_1 has to be considered a lower bound for the true effect. Section C.2 in the Appendix discusses this in detail.

3.2 OLS estimates are biased downwards

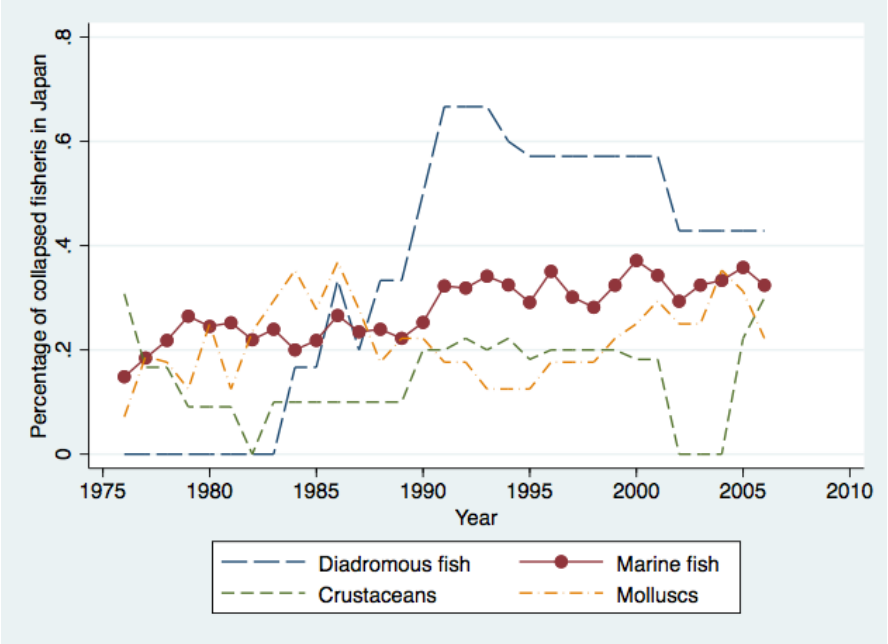
An OLS regression would underestimate the effect of exports on fisheries collapse. This holds true even if we only observe fisheries up to the point in which they collapse. The downward bias results from the fact that both exports in period $t-1$ and the dependent variable are correlated with the stock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

3.3 Collapse of fisheries within Japan's EEZ as an instrument

To address this endogeneity, the collapse of fisheries within Japan's EEZ is used as an instrument for fisheries exports in countries that do not share stocks with Japan. The instrument is species-year specific and the analysis exploits substantial variation in Japanese fisheries collapse across time and species.

Japan experienced a drastic increase in the collapse of fisheries during the sample period. The proportion of collapsed fisheries within Japan's EEZ increased from 13 percent in 1976 to 28 percent in 2006. Species collapse throughout the sample period and almost all species categories are affected.[15] Figure 4 uses data from the Sea Around Us Catch Database to show the percentage of collapsed species in Japan's EEZ for different species categories. The figure reveals variation across time and species categories.

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



Author's calculations based on data from the Sea Around Us Catch Database.

This paper argues that the collapse of a species i in Japan has a strong influence

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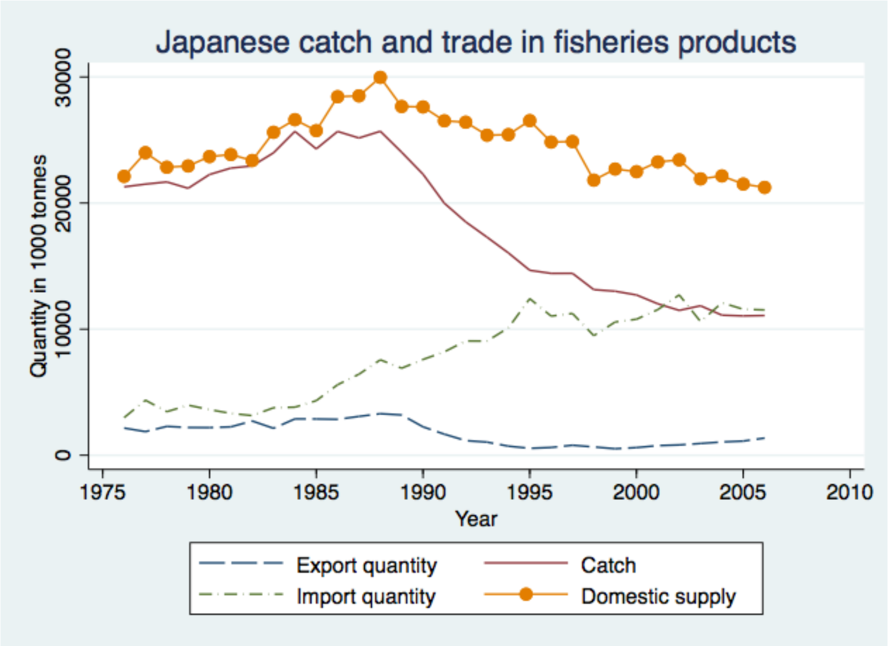
[15] Column 3 of Table 11 in the Appendix shows the number of individual species that collapse in Japan during the sample period by species category.

on exports of species i in other countries, since Japan is both a large supplier and consumer of seafood. When Japanese catch declines as a result of the collapse, Japan sources more seafood products on foreign markets. The resulting increase in Japanese import demand raises the world market price for species i, spurring exports of species i in the rest of the world. Therefore, a collapse in Japan generates an export demand shock in other countries. Data from Japanese fisheries suggest that this mechanism is at work.

Japan was the largest producer of fishery products until the late 1980s as its contribution to global marine catch hovered between 15% to 20%. Yet this masks variation across species categories and species. Figure 10 in the Appendix shows that the majority of the world's sea urchins, sea cucumbers and other miscellaneous aquatic animals, as well as almost half of the molluscs were caught in Japan's EEZ.

Figure 5: Japanese catch and trade in fishery products



Total exports, imports, catch and domestic supply of marine fish and other fishery products, excluding freshwater fish. Domestic supply is defined as production-exports+imports+changes the government's or retailers' stocks of harvested fish. The underlying data are from the FAO food balance sheets.

Total catch by Japanese vessels declined over the course of the sample period (Figure 5),[16] but an increase in imports guaranteed a stable supply of fishery

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[16] Figure 5 is based on FAO data. The FAO maps catch to countries based on the flag of the

products in Japan. The green dashed line in Figure 5 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 supply of fishery products for domestic utilitization[17] remained relatively stable as demonstrated by the yellow line in Figure 5. Japan remains the second largest market for seafood products after China.[18]

3.4 Exclusion restrictions are satisfied

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

Since neighbouring countries are likely to share fish stocks, all countries with Exclusive Economic Zones (EEZ)[19] adjacent to Japan are excluded from the sample. The sample does not include Russia, North and South Korea, China, Taiwan, the Philippines and the Northern Mariana Islands. Excluding neighbouring countries also reduces the risk of ecosystem linkages between fisheries within Japan's waters and fisheries in exporting countries confounding the results.

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fishing vessels. Japanese vessels may fish in Japan's EEZ or in international waters. The Sea Around Us Catch Database, which is used to define collapse in this paper, maps catch to country's EEZ irrespective of the flag of the vessel that caught the fish. Sea Around Us catch data show the same decline in catch as the FAO data used to generate Figure 5.

[17] The FAO food balance sheets define domestic supply as production-exports+imports+stock changes. Stock variation "comprises changes in government stocks, in stocks with manufacturers, importers, exporters, other wholesale and retail merchants, transport and storage enterprises and in stocks on farms" (FAO, 2021b). Reported stock variation is zero for most years and most categories of fisheries products.

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

[19] 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.

Some species migrate large distances and therefore stocks of migratory species could plausibly be fished by both Japan and another country a long way from Japan. Data from this second country would not be excluded from the sample if it is not one of Japan's neighbours. Therefore, the sample does not include fish species which are known to migrate large distances (e.g. tunas) nor species with extensive distributions in the high seas. To be precise, the analysis excludes highly migratory fish species listed in Annex 1 of the UN Convention of the Law of the Sea (UN General Assembly, 1982) as well as fish species with ranges in the high seas and all straddling fish stocks[20] in the area surrounding Japan (FAO fishing area 61).

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

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

3.5 Why did Japanese fisheries collapse?

Anecdotal evidence suggests that the collapse in Japan is not driven by shocks that could also affect exporting fisheries in the sample. Makino (2011) highlights that most Japanese fisheries collapse as a result of high demand for fishery products (indeed, FAO data show that per capita seafood consumption in Japan was about 7 times the world average in 1976), overcapacity in the Japanese fishing industry and inadequate fisheries management. The collapse is mostly driven by domestic factors and often precedes the collapse in other countries. Where available, anecdotal evidence suggests that overfishing was responsible for the collapse of fisheries within Japan's waters.[21]

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

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

4 Data and summary statistics

This section presents key features of the detailed country-species-year level dataset measuring fisheries collapse, prices, and trade in fishery products. An extensive description of the variables and all data sources is available in Online Appendix Section B.

4.1 Data

Fishery collapse in the exporting country's EEZ. The dependent variable, Collapsed_{ikt}, is a dummy variable that equals 1 if catch of species i within the EEZ of country k in year t is less than 10% of ik's maximum historical catch recorded between 1950 and year t. This catch-based definition follows a common approach used in the literature (see e.g. Worm et al., 2006; Costello et al., 2008). Species are defined at the level of the 3-alpha code in the ASFIS List of Species for Fishery Statistics Purposes (FAO, 2021a).

A fishery's collapse is inferred based on catch data from the Sea Around Us Catch Database (Pauly et al., 2020). To construct the Sea Around Us Catch Database, Watson et al. (2004) use FAO catch data and map species level catch to each country's EEZ using ancillary information on the distribution of commercially exploited species and fishing access agreements. The spatial distribution of species is useful in mapping catch to spatial grid cells, since species can only be caught where they occur. Moreover, countries can only fish within their own 200 nm EEZs or on the high seas, unless they have a fishing access agreement with another country. The data and the mapping are described in more detail in the data appendix and in Watson et al. (2004).[22] The Sea Around Us Catch Database contains species-level information on catch from 1950 to 2006.

Collapse in Japan's EEZ. The instrument, Col. Japan_{it}, is a dummy variable that takes the value of 1 if catch of fish species i within Japan's EEZ in year t is less than 10% of the maximum historical catch of species i recorded in Japan between 1950 and year t. The analysis dataset contains species that are not caught by Japan. When Japan does not report catch statistics for a particular species, the instrument takes a value of 0 for that species throughout the sample period.

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

Previously collapsed. The control variable "Prev. Collapsed" takes a value of 1 if the fishery *ik* (defined at the country-species-level) has collapsed in the past.

Species-level exports. 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 catch data at the country-species-year level. The matching is based on the species' common name listed in the trade data. The analysis only makes use of export data that clearly identify the exported species (e.g. haddock or Atlantic cod). Those data can be matched one-to-one to the species-level catch data. Some export statistics are reported in aggregate categories applying to several species (e.g. "mussels"). Since it is not possible to know which mussel species are exported, those export data are not used for the analysis.

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

Prices. This paper uses both ex-vessel prices and export prices to measure the effect of an exogenous increase in the price on the collapse of fisheries. All prices are measured in constant 2005 US$ per kilo.

Ex-vessel prices. Ex-vessel prices measure the price fishermen get for their catch when the fish is landed. Fishermen's incentive to fish should be directly impacted by those ex-vessel prices. Ex-vessel prices at the country-species-year level are from Swartz et al. (2012), who collect a comprehensive dataset of ex-vessel prices and estimate missing price data using species' annual average price across countries and purchasing power parity adjustments (see Online Appendix Section B for details). About 70 percent of the observations in the analysis dataset are estimated and hence potentially measured with error. Therefore, the paper also uses export prices, which are calculated from species-level trade data.

Export prices. Export prices are calculated as export values divided by export quantities using the country-species-level export data described above.

The analysis dataset is an unbalanced panel covering 93 countries and 108 different marine species. This paper uses data from coastal countries not neighbouring Japan. The sample spans all countries shaded in red or blue in Figures 7 and 8. Column 2 of Table 11 in the Appendix shows the number of distinct country-species combinations in the sample by species group.

4.2 Summary statistics

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

Exports of fishery products grew by 277 percent over the sample period. The total export quantity of fishery products in the sample used for this study increased from 1.1 million tonnes in 1977 to 4.2 million tonnes in 2006 (see Figure 6).[23]

This export growth coincides with an increasing prevalence of fisheries collapse in exporting countries. The red line in Figure 6 shows that the proportion of collapsed fisheries increased from 8 percent in 1976 to 25 percent in 2006. Fisheries collapse throughout the sample period. The green line in Figure 6 indicates that between 2 and 8 percent of the fisheries collapse every year. The summary statistics in Table 1 show that 4.7 percent of the observations represent collapsing fisheries, i.e. fisheries in the year they 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.

Table 1: Summary statistics

	(1) Mean	(2) Overall Sd.	(3) Between Sd.	(4) Within Sd.
Collapsed	0.047	0.211	0.155	0.189
Export quantity (lag)	9.987	38.885	24.292	22.718
Export quantity (lag, ln)	6.566	2.665	2.649	1.109
Ex-vessel price (lag, ln)	0.579	1.147	1.040	0.514
Export price (lag, ln)	1.251	0.991	0.951	0.408
Catch share (lag)	0.104	0.305	0.208	0.191
Collapsed Japan (lag)	0.117	0.322	0.229	0.238
Observations	8876	8876	8876	8876

Between Sd: Standard deviation between country-species combinations

Within Sd: Standard deviation within country-species combinations

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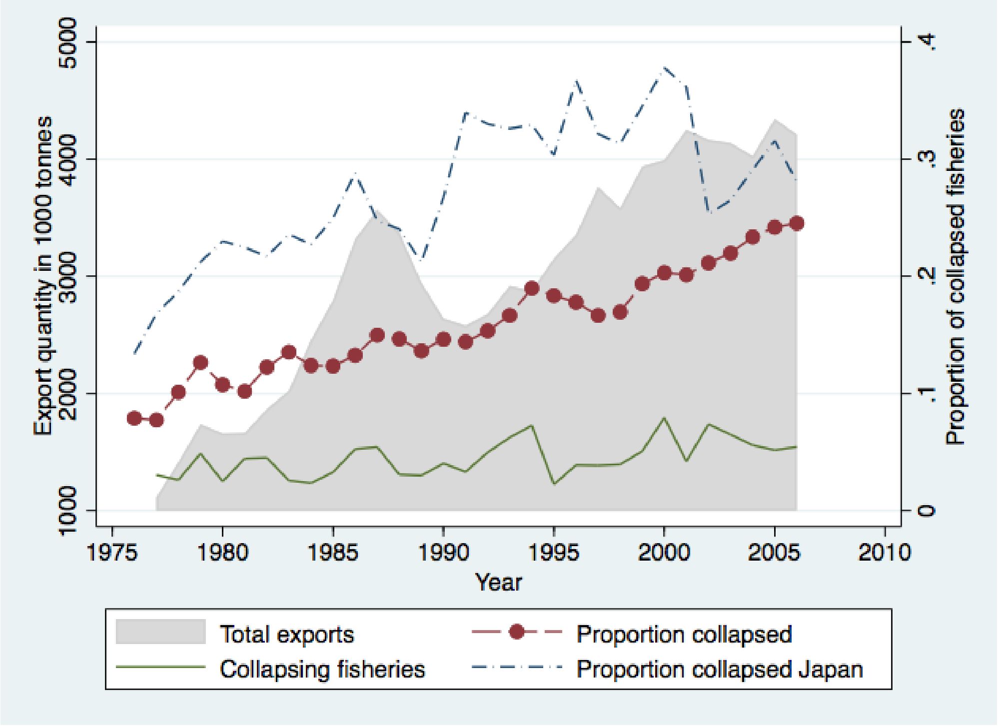
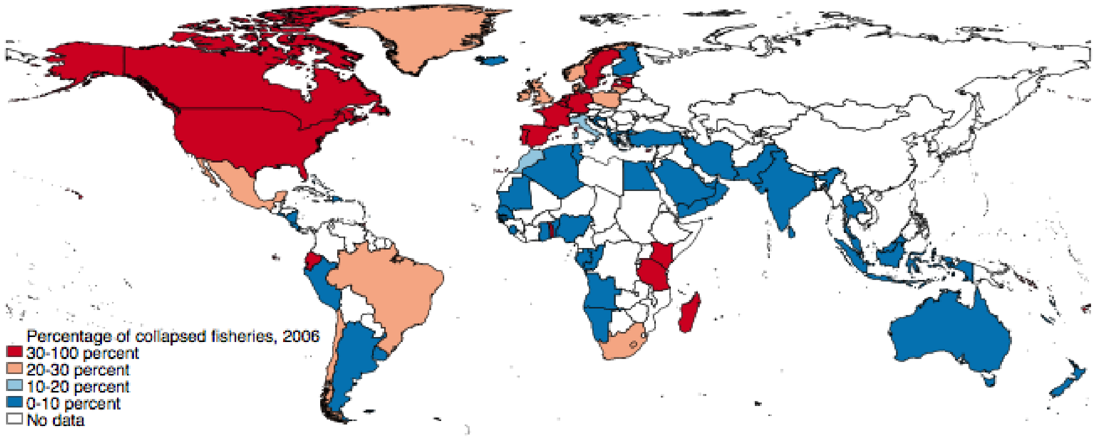
[23] Total exports of all fishery products, including exports of species which are not in the sample grew by almost 400 percent over the same time period.

Figure 6: Fisheries collapse and export quantities in the sample



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

Figure 7: Proportion of collapsed fisheries at the end of the sample period



Note: The figure is based on data from the Sea Around Us Catch Database. Only data from fisheries in the analysis sample are used to construct this figure.

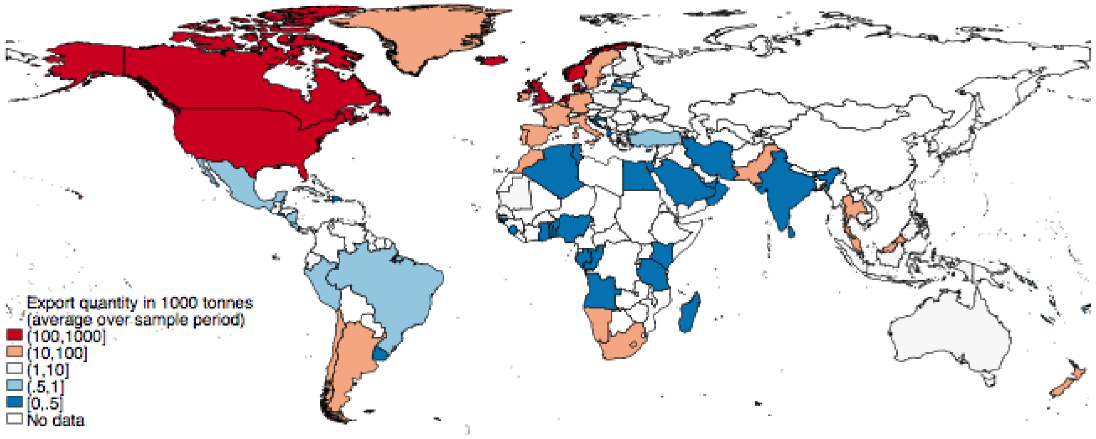
Fisheries collapse is more prevalent in Japan than in the rest of the world. The green dashed line in Figure 6 reveals that the proportion of collapsed fisheries in Japan surges from 13 percent in 1976 to 28 percent in 2006. Japanese stock assessments confirm the poor state of Japanese stocks. 43 out of the 90 assessed stocks within Japan's EEZ were categorized as being at low levels in 2007 (Makino, 2010).

Countries with high exports are also the ones with the highest proportion of collapsed fisheries in 2006. Such a pattern can easily be seen by comparing Figure 7, which shows the proportion of collapsed fisheries in 2006 amongst fisheries in the sample, with Figure 8, displaying average country-level exports. Average exports are defined as $(\sum_{t=1976}^{T=2006}\sum_{i\in I}\text{Exports})/31$, where I is the set of all fisheries within a country in the sample.

5 Results

The results in this section show that the collapse of fisheries in Japan's EEZ raises ex-vessel prices and exports. Instrumental variable regressions confirm the paper's hypotheses. An increase in the ex-vessel price raises exports in the same year and the probability of collapse in the subsequent year. Furthermore, the results show that exporting significantly raises the probability of fisheries collapse. This is

Figure 8: Countries' annual total export quantity, averaged over a 31-year sample period



especially the case for fisheries that are not regulated via catch share programs.

5.1 Collapse in Japan associated with higher prices and exports

The results show a significant conditional correlation between the collapse in Japan and ex-vessel prices as well as exports.

A collapse of a species in Japan's EEZ is associated with a statistically significant increase in the ex-vessel price in exporting fisheries by 6 percent (Column 1 of Table 2). The export price is positively correlated with the collapse in Japan, but the coefficient estimate is smaller and not statistically significant. Hence, the collapse in Japan's EEZ would not be a suitable instrument for the export price. Column 3 of Table 2 also shows that the collapse in Japan's EEZ is associated with a large, but statistically insignificant increase in an exporting fishery's catch by 12.4 percent.

The collapse of a Japanese fishery is associated with a large and statistically significant increase in exports of the affected species elsewhere. Column 4 of Table 2 reveals that exports from fisheries not shared with Japan increase by 19.3 percent when the Japanese fishery collapses. To put the effect size into perspective, Table 12 in the Appendix shows that the collapse in Japan is associated with an increase in Japanese imports by 9,651 tonnes or 2.9 percent. Those are sizeable effects, but they are not statistically significant. It is important to highlight that Table 12 shows conditional correlations between the collapse in Japan and Japanese imports

Table 2: Correlation between collapse in Japan's EEZ and prices, catch and exports

	(1) Price	(2) Export price	(3) Catch	(4) Exports
Col. Japan	0.060*	0.014	0.124	0.193***
	(0.035)	(0.045)	(0.084)	(0.064)
Controls	No	No	No	No
FEs: γ_{rt}, γ_i, γ_k	Yes	Yes	Yes	Yes
No. of clusters	107	106	107	106
Observations	8876	8461	8876	8468

This table shows the conditional correlation between a collapse in Japan's Exclusive Economic Zone and the ex-vessel price (Column 1), the export price (Column 2), catch (Column 3) and exports (Column 4). All dependent variables are logged. Standard errors (clustered at the species level) in parentheses.

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

rather than causal effects.

The collapse in Japan is most strongly correlated with the export quantity (see Table 2). This means that it is most suitable as an instrument for exports. Therefore, the analysis focuses on exports as the main regressor of interest. Section 5.4 also analyses the effect of an increase in the ex-vessel price on catch, exports and the probability of a collapse as a direct test of Hypotheses 1(a) and 2, but the collapse in Japan is a weaker instrument for the ex-vessel price.

5.2 Exporting leads to the collapse of fisheries

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

5.2.1 Benchmark OLS regression

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

Table 3: OLS and baseline results

	(1)	(2)
	OLS	IV
Dependent variable:	Collapse	Collapse
L.Ln(Export quantity)	-0.003**	0.118**
	(0.002)	(0.049)
Controls	Yes	Yes
Fixed effects: γ_{rt}, γ_i, γ_k	Yes	Yes
IV	-	L.Col. Japan
1st stage F-Stat		10.388
Anderson-R. p-value		0.004
No. of clusters	107	107
Observations	8876	8876

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

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

evidence to support this.

5.2.2 Assessment of the instrument

The collapse of fisheries in Japan is strongly correlated with an increase in exports from countries not sharing stocks with Japan (see Section 5.1 and Column 4 of Table 2) and it is a sufficiently strong instrument for exports. The Kleibergen-Paap first stage F-statistic[24] of 10.4 indicates that the instrument is strong based on Staiger and Stock (1997)'s definition. According to this definition, an instrument is weak if the first stage F-statistic is below 10.[25]

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

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[24] The Kleibergen-Paap F-statistic is the relevant first stage F-statistic for the results reported in this paper since standard errors are clustered.

[25] A more formal test by Stock and Yogo (2005) shows that it is possible to reject the null-hypothesis that the asymptotic 2SLS bias exceeds 15% of the OLS bias.

tests with a first-stage F-Statistic below 10. In this case, the coefficient estimate for β_1 should be considered a lower bound of the true effect of exports, since it is well known that the 2SLS estimates are biased downward in the direction of the OLS estimates if instruments are weak.

5.2.3 IV results: Exporting leads to the collapse of fisheries

The baseline instrumental variable results reveal that exports have a large effect on the collapse of fisheries. Column 2 of Table 3 shows that an increase in exports by one percent raises the probability of a fishery's collapse in the following year by 0.118 percentage points. This is a sizeable effect: an increase in logged exports by one standard deviation raises the probability of a collapse by 31 percentage points.

This effect is large but realistic in light of the observed trends in export growth and fisheries collapse. Exports in the median fishery grew by 52 percent between 1991 and 2006 (half of the sample period). Given the coefficient estimate for exports ($\hat{\beta}_1 = 0.118$), this export boost raised the probability of a collapse by around 6 percentage points (52*0.118).[26] A comparison with the rate of fisheries collapse in the sample helps to put this number into perspective. I calculated the rate of collapse for fisheries that report export data in 1991 and 2006 and are not collapsed in 1991. Twenty percent of these fisheries collapsed at least once between 1991 and 2006.[27] Hence, median export growth predicts almost one third of the observed rate of collapse in the sample.

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

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[26] Note that this number has to be interpreted with caution. The coefficient estimate $\hat{\beta}_1 = 0.118$ captures the effect of a marginal increase in exports on the probability of collapse in the following year. The 52 percent increase in exports happens over a time frame of 15 years and is not marginal. Nevertheless, it is helpful to put the effect size into perspective.

[27] Some of those fisheries may recover. The percentage of collapsed fisheries increased by 10 percentage points between 1991 and 2006.

5.3 Fisheries without catch share programs are affected

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

To analyse how fisheries management affects the relationship between exports and fisheries collapse, the sample is split into catch share fisheries and fisheries that are not regulated via catch share programs.[28] Catch share programs are fisheries management tools that allocate secure fishing rights to individual entities. Most of the catch share programs are individual transferable quotas (ITQs) or similar quota-based programs allocating fishing rights to a proportion of a total allowable catch. But a small number of catch share programs are area-based and allocate the privilege to fish in specific areas to groups or individuals. These programs are called Territorial Use Rights for Fishing programs (TURFs). Fisheries without catch share programs may be subject to other regulatory measures, but there are no global datasets recording these measures.

Exports raise the risk of a collapse for fisheries without catch share programs: the probability of a collapse increases by 0.13 percentage points as exports increase by one percent (Column 1 of Table 4). Those results are based on a sample including fisheries that are not regulated via catch share programs in year t but potentially adopt those programs later on. In a sample of fisheries that are never regulated via catch share programs, an increase in exports by one percent raises the probability of a collapse by 0.11 percentage points (see Column 2 of Table 4).

Results from a sample of fisheries without catch share programs represent a conservative estimate of the effect of exports on open access fisheries. The coefficient estimates in Columns 1 and 2 of Table 4 present the average effect of exports on open access fisheries and fisheries subject to regulatory measures other than catch share programs. The effect of exports is likely to be lower than 0.11 for regulated fisheries and higher for open access fisheries.

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[28] The analysis makes use of data on catch share programs from the Environmental Defense Fund (EDF). More information on the data is available in the online data appendix in Section B.8.

Table 4: Fisheries without catch share programs collapse as a result of exports

	(1)	(2)	(3)	(4)
Sample:	Presently no catch share	Never under catch share	Catch share	All
Dependent variable:	Collapsed	Collapsed	Collapsed	Collapsed
L.Ln(Export quantity)	0.133**	0.108***	-0.093	0.112**
	(0.055)	(0.034)	(0.066)	(0.046)
L. ln(Exports) × L.Catch share				0.008
				(0.033)
L.Catch share				-0.132
				(0.283)
Controls	Yes	Yes	Yes	Yes
FEs γ_{rt}, γ_i, γ_k	Yes	Yes	Yes	Yes
1st stage F-Stat	10.281	13.121	1.910	10.097
Anderson-R. p-value	0.004	0.002	0.083	0.006
No. of clusters	107	93	47	107
Observations	7881	6448	992	8876

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

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

The results provide tentative evidence that fisheries which are already regulated via catch share programs are shielded from potentially negative effects associated with exporting. In the sample of catch share fisheries, the first stage regression reveals that a collapse in Japan does not lead to a significant increase in exports. Moreover, the results from the second-stage regression in Column 3 of Table 4 show that exports do not spur a collapse of catch share fisheries. The coefficient estimate is negative, suggesting that, if anything, exports reduce the probability of collapse. However, the coefficient estimate is not statistically significant. Moreover, the weak correlation between the instrument and exports in the sample of catch share fisheries implies that the second-stage regression results may be biased downwards and have to be interpreted with caution.

It is possible that catch share fisheries differ systematically in their underlying characteristics from fisheries without catch share programs. Hence, the benefits that are associated with catch share programs may not translate to fisheries that are currently not regulated via catch share programs. In an attempt to address this concern, Table 4 also presents results for the full sample and includes an interaction term between exports and the catch share dummy variable as a regressor. The collapse in Japan interacted with the catch share dummy variable is used as a second instrument.

The estimates in Column 4 of Table 4 confirm that exports significantly raise the probability of a collapse in fisheries without catch share programs by 0.11 percentage points. They also suggest that the effect of exports on fisheries collapse does not differ between catch share fisheries and other fisheries. The coefficient estimate for the interaction term is small in magnitude and not statistically significant. This means that potential benefits of existing catch share programs may not translate to all fisheries.

The coefficient estimate for the interaction term "L. ln(Exports) × L.Catch share" would be biased downwards if fisheries at risk of collapse were more likely to adopt catch share programs. However, robustness checks illustrate that there is no evidence of such a downward bias. Table 13 in the Appendix show results with more fine grained country-year and country-species fixed effects. Those fixed effects control for potential omitted variables affecting both the risk of collapse and the probability of management. None of the results in Table 13 suggest that the adoption of catch share programs significantly reduces the risk of collapse resulting from higher exports. Furthermore, Table 14 in the Appendix shows that the collapse of a fishery in period $t - 1$ does not make the adoption of a catch share program for that fishery more likely in period t.

The results presented in Columns 3 and 4 of Table 4 are partly contradictory. More research with a larger sample of exporting catch share fisheries is necessary to fully understand whether catch share programs shield exporting fisheries from collapse.

5.4 Effect of the price on catch, exports and collapse

The use of price data allows for the most direct test of the paper's hypotheses. This section provides support for Hypotheses 1(a) and Hypothesis 2. The results suggests that an exogenous increase in the ex-vessel price leads to an instantaneous increase in exports and a higher probability of collapse in the following year.

For the purpose of the empirical analysis, the price is considered endogenous. Some of the fisheries in the sample are large fisheries, which can influence the equilibrium price on the world market through changes in their export supply.[29] A reduction in catch in a large exporting fishery (resulting from a lower stock) reduces export supply and raises the world market price. As a result of this reverse causality, the coefficient estimate for the price would be biased downwards in OLS regressions looking at the effect of the price on catch or exports. The price is also endogenous when the probability of collapse is the outcome of interest, since stocks are unobserved. The stock size affects catch and the price and it also determines the probability of collapse in the following year.

The collapse in Japan is used as an instrument. The collapse in Japan is significantly correlated with the ex-vessel price but not with the export price (see Table 2). The collapse in Japan would be a weak instrument for the export price. Hence, the analysis focuses on the ex-vessel price as a regressor. The use of the collapse in Japan as an instrument for the ex-vessel price also addresses the potential attenuation bias associated with measurement error in ex-vessel prices. The results shown here are based on the same sample of exporting fisheries as the baseline regression.

Table 5: Effect of the price on catch, exports and collapse

	(1) Ln(Catch)	(2) Ln(Exports)	(3) Collapse
Ln(Price)	2.030	5.224	
	(2.218)	(4.329)	
L.Ln(Price)			0.484
			(0.387)
Controls	Yes	Yes	Yes
Fixed effects: γ_{rt}, γ_i, γ_k	Yes	Yes	Yes
1st stage F-Stat	2.108	1.440	2.322
Anderson-R. p-value	0.247	0.003	0.004
No. of clusters	107	105	107
Observations	8876	8467	8866

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

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[29] The (world market) price is exogenous for small exporting fisheries. Those fisheries supply a sufficiently small share of the global market such that a shift in the fishery's export supply does not affect the world market price. An assessment of whether countries are small or large on the world market of a particular fish species would require estimating elasticities (see e.g. Broda et al., 2008), but this is beyond the scope of this paper. Therefore, this paper assumes that prices are potentially endogenous for any of the fisheries in the sample.

According to Hypothesis 1(a), an exogenous increase in the price leads to an instantaneous increase in catch and exports in an open access fishery. The results in Table 5 tentatively confirm this: an increase in the ex-vessel price by one percent leads to an increase in catch by 2 percent (Column 1) and an increase in exports by 5 percent (Column 2). However, with a first stage F-Statistic of 2.1 and 1.4, respectively, the collapse in Japan is not a very strong instrument for the price. This means that the coefficient estimates might be biased downward in the direction of the OLS estimates. Furthermore, it implies that inference has to be based on the Anderson-Rubin test, which is robust to weak instruments. Based on the p-value from this test (displayed in the third but last row of Table 5), only the estimated effect of the price on the export quantity is statistically significant.

Hypothesis 2 states that an increase in the price can lead to the collapse of fisheries and the results corroborate this. Column 3 of Table 5 shows that an increase in the ex-vessel price by 1 percent raises the probability of collapse in the following year by 0.48 percentage points. The coefficient estimate is statistically significant based on weak instrument robust inference.

Since the collapse in Japan is a weak instrument for the ex-vessel price, all further analyses using the collapse in Japan as an instrument will use exports as the regressor.

6 Dynamics

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

6.1 Longer lags and maximum historical exports

Longer lags of exports can shed light on the dynamic relationship between exports and the collapse of fisheries. Column 1 of Table 6 shows that an increase in exports in period $t-2$ is estimated to raise the probability of a fishery's collapse in period t by 0.15 percentage points. This estimate is slightly higher than the short-term effect estimated in the baseline regression.[30] Unfortunately, it is not possible to estimate a distributed lag model, since this would require an instrumental variable for every lag of exports. Using several lags of the collapse in Japan as instruments yields weak instruments due to the high correlation between the different lags of the collapse in Japan.

Instead of using lags of exports, it is possible to study whether a higher export peak raises the probability of a collapse once the peak has passed. The theoretical model predicts that an increase in the price leads to a spike in exports. This can cause a collapse in the future. The time that elapses between the export peak and the collapse depends on fishery characteristics. The export peak can be captured empirically as the fishery ik's maximum historical exports recorded up to year t. Column 4 of Table 6 shows how this variable affects the probability of a collapse.

The results reveal that an increase in maximum historical exports by 1 percent raises the probability of a fishery's collapse by 0.15 percentage points (see Column 4 of Table 6). The coefficient estimate is statistically significant based on weak instrument robust inference. Column 5 of Table 6 suggests that fisheries collapse soon after the peak in exports. The results show a negative relationship between the years since the peak in exports and the collapse of the fishery.

6.2 Biomass data and dynamic panel data model

This section uses biomass data to test whether an increase in the price and exports leads to a smaller resource stock in future periods (Hypothesis 1(b)). The stock in any period is a function of the stock in the previous period, of resource growth and catch. These dynamics can be approximated empirically using a dynamic panel data model to explain stock biomass as a function of past stock biomass and prices or exports.

The estimation is based on biomass data from the RAM legacy stock assessment database (Ricard et al., 2012), where available. Due to the sparsity of stock assessments, these data are supplemented with estimates of stock biomass from Costello et al. (2016).[31] The results provide very tentative, albeit statistically

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[30] This paper does not find a significant effect of exports in period $t-3$ on a fishery's collapse in period t (see Column 2 of Table 6). Exports in period $t-4$ are estimated to raise the probability of a collapse in period t by 0.14 percentage points. In all of those regressions, the collapse of a Japanese fishery in period $t-l$ is used an instrument for exports in period $t-l$.

[31] I am very grateful to Chris Costello and Tyler Clavelle for access to these data. The estimates of stock biomass are based on catch statistics, fish species' life history data and a structural

Table 6: Different lags of exports

	(1) Collapse	(2) Collapse	(3) Collapse	(4) Collapse	(5) Collapse
L2.ln(Exports)	0.149** (0.061)				
L3.ln(Exports)		0.107 (0.112)			
L4.ln(Exports)			0.137 (0.123)		
Ln(Max. Exp. up to t)				0.149* (0.077)	
Years since max. exp					-0.027* (0.014)
IV	L2.Col. Jap.	L3.Col. Jap.	L4.Col. Jap.	L.Col. Japan	L.Col. Japan
1st stage F-Stat	6.573	2.143	1.895	4.045	10.221
Anderson-R. p-value	0.001	0.135	0.039	0.005	0.002
No. of clusters	104	101	100	111	111
Observations	8324	7812	7340	11237	10353

Ln(Max. Exp. up to t) represents the natural logarithm of the maximum historical export quantity recorded in fishery *ik* up to time t. Years since max. exp measures the years since the last export peak. Standard errors (clustered at the species level) in parentheses. The p-value of the Anderson and Rubin (1949) test (Anderson-R. p-value) provides weak instrument robust inference.
* p<0.1, ** p<0.05, *** p<0.01

insignificant, evidence that higher prices or exports are associated with a reduction in stock biomass. However, the results should be taken with a pinch of salt. Biomass is estimated for the majority of the fisheries and hence measured with error.

6.2.1 An alternative empirical strategy to capture dynamics

The dynamic effect of exports on fish stocks can be modelled in more detail using biomass data. This section uses a dynamic panel data model in which the dependent variable is the natural logarithm of stock biomass of fish species i in country k in year t, $ln(S_{ikt})$. Stocks in period t are considered a linear function of the natural logarithm of stocks in period $t-1$, $ln(S_{ik,t-1})$ and of the natural logarithm of

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fisheries modelling approach. Details on the data are available in the online data appendix in Section B.10.

the export quantity in period $t-1$, $ln(\text{Exports})_{ik,t-1}$.[32] Supplying fish to export markets requires a higher harvest. Therefore, exports in period $t-1$ are expected to have a negative effect on stocks in period t.

Estimation is based on Equation 8, in which the error term consists of a country-species-specific time-invariant component η_{ik} and the time-varying component ϵ_{ikt}. η_{ik} also captures the effect of time-invariant differences in growth rates across species and fisheries. The empirical model includes year fixed effects γ_t and controls for fisheries management via catch share programs, as represented by the dummy variable "Catch share$_{ikt-1}$".

$$ln(S_{ikt}) = \alpha_1 ln(S_{ikt-1}) + \alpha_2 ln(\text{Exports})_{ikt-1} + \alpha_3 \text{Catch share}_{ikt-1} + \gamma_t + \eta_{ik} + \epsilon_{ikt} \tag{8}$$

The short-term effect of an increase in the export quantity on biomass is captured by the coefficient α_2 in Equation 8. Based on Hypothesis 1(b), an increase in exports in period $t-1$ is associated with a reduction in stock biomass in period t and in future periods. To shed more light on the dynamic effect of prices on stock biomass, this section also shows results including $ln(\text{Exports})_{ikt-2}$ and $ln(\text{Exports})_{ikt-3}$ as additional regressors. Moreover, it shows results using the price rather than exports as a regressor.

The long-term effect of exports on biomass in Equation 8 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 8 is estimated using an Arellano-Bond estimator. Arellano-Bond estimation uses the first difference of Equation 8 (i.e. $\Delta ln(S_{ikt}) = \alpha_1 \Delta ln(S_{ikt-1}) + \alpha_2 \Delta ln(\text{Exports})_{ikt-1} + \alpha_3 \Delta \text{Catch share}_{ikt-1} + \Delta\gamma_t + \epsilon_{ikt}$, where Δ is the first-difference operator). First-differencing eliminates the time-invariant component of the error term, η_{ik}. A consistent estimator is obtained through generalized methods of moments estimation of this first-differenced equation using values of biomass, exports and the catch share indicator lagged two periods or more as instruments. To be precise, this paper uses 6 lags of $ln(S_{ikt-1})$, 3 lags of $ln(\text{Exports})_{ikt-1}$, and 3 lags

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[32] The distributions of biomass and exports are highly skewed (see Section C.5). Hence, the analysis uses a log-log specification which gives less weight to outliers.

of Catch share$_{ikt-1}$ as instruments for the first difference equation.[33] Those lagged values of biomass, exports and the catch share indicator are valid instruments since they are uncorrelated with the error term ϵ_{ikt}.

In line with the Hypothesis 1(b), the paper also looks at the effects of ex-vessel prices on biomass using the approach outlined above and replacing the regressor $ln(\text{Exports})_{ikt-1}$ with $ln(\text{Price})_{ikt-1}$. When prices are used as regressor, the analysis uses 6 lags of $ln(S_{ikt-1})$, 5 lags of $ln(\text{Price})_{ikt-1}$, and 4 lags of Catch share$_{ikt-1}$ as instruments for the first difference equation. With those respective instrument matrices, the usual specification tests suggest that the model is correctly specified.[34]

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

The identification assumptions for the Arellano-Bond estimation differ from the identification assumptions used for the IV estimation. Stocks are observed and, hence, there is no omitted variable bias due to a lack of information on stocks. Since lags of biomass, exports and catch shares can be used as exogenous instruments, it is not necessary to use the collapse in Japan's EEZ as an instrument. Therefore, it is also possible to include Japan's neighbours in the analysis sample.[35] However, the sample does not include highly migratory and high-sea fish stocks and it only includes exporting fisheries.

6.2.2 Results

The results provide tentative but statistically insignificant evidence that exporting reduces stock biomass, both in the short- and long-term. The short-term effect is captured by the coefficient estimate for the export quantity in Column 1 of Table 7. The results suggest that an increase in exports by one percent reduces stock

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

[34] 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 Table 7. Moreover, the p-value for the Hansen test, displayed in the penultimate row of Table 7, shows that the null-hypothesis of valid moment conditions cannot be rejected.

[35] The results follow through if the collapse in Japan's EEZ is included as an additional instrument and Japan's neighbours as well as fisheries that are potentially shared with Japan are excluded from the sample.

Table 7: Dynamic model for the effect of exports and price on biomass

	(1) Ln(Biomass)	(2) Ln(Biomass)	(3) Ln(Biomass)	(4) Ln(Biomass)
L.Ln(Biomass)	0.702***	0.513**	0.634***	0.641***
	(0.191)	(0.231)	(0.165)	(0.189)
L.Ln(Export quantity)	-0.003	-0.015		
	(0.014)	(0.039)		
L2.Ln(Export quantity)		-0.005		
		(0.013)		
L3.Ln(Export quantity)		-0.005		
		(0.006)		
L.Ln(Price)			-0.001	-0.015
			(0.029)	(0.066)
L2.Ln(Price)				-0.007
				(0.029)
L3.Ln(Price)				-0.012
				(0.021)
L.Catch share	0.322	0.007	-0.022	-0.150
	(0.439)	(0.551)	(0.332)	(0.316)
Long-run effect	-0.010		-0.004	
Instrument #	42	40	45	45
AR(1) p-value	0.000	0.007	0.000	0.000
AR(2) p-value	0.672	0.814	0.722	0.592
Hansen test p-value	0.236	0.105	0.305	0.113
Observations	7843	6721	7828	7684

Estimation is based on an Arellano-Bond estimator. Standard errors (clustered at the country-species level) in parentheses. Standard errors for the long-term effect are calculated using the delta method. AR(1) p-value and AR(2) p-value show the p-values for the Arellano-Bond test for first- and second-order serial autocorrelation in the first-differenced error term, respectively.
* $p<0.1$, ** $p<0.05$, *** $p<0.01$

biomass by 0.003 percent in the following period, but the coefficient estimate is not statistically significant. In the long-term, an increase in exports by one percent is estimated to reduce stock biomass by 0.010 percent (see lower half of Table 7). This tentatively corroborates the finding that exporting has a negative effect on fish stocks. Column 2 of Table 7 suggests that the effect of an increase in exports is strongest in the period following the increase in exports. The coefficient estimates for longer lags of exports are smaller.

Results in Columns 3 and 4 of Table 7 provide tentative evidence for Hypothesis 1(b). Column 3 of Table 7 suggests that an increase in the price by one percent leads to a small and statistically insignificant reduction in biomass in the following year by 0.001 percent. Column 4 shows that an increase in the price is associated with a statistically insignificant reduction in biomass in the years following the increase in the price.

7 Sensitivity analysis

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

Further robustness tests are available in the Empirical Appendix C. Section C.1 shows that the results follow through if the collapse of the Japanese fishery is interacted with the exporting country's distance from Japan. The estimated effect of exports has to be considered a lower bound of the true effect in case of substitution across species. Section C.2 explains this in detail and shows that there is no evidence of substitution to other species in the same family. However, more complicated substitution patterns cannot be ruled out. Section C.3 discusses measurement error in fisheries collapse and shows that the results are largely robust to changing the definition of fisheries collapse. The estimated effect of exports on the probability of collapse is slightly higher with alternative sets of fixed effects, as demonstrated in Section C.4. Section C.5 shows that the distribution of exports is skewed and results are affected by outliers in regressions with exports in levels. The paper's findings follow through if net exports are used as an alternative measure for trade openness (Section C.6). Species that are suitable for aquaculture production do not seem to be depleted due to exports, as demonstrated in Section C.7. Section C.8 shows that there is no statistically significant difference in the effect of exports across fisheries that have collapsed in the past and fisheries that have not collapsed in the past. Finally, Section C.9 shows that the estimated effect of exports on the probability of collapse is even higher than in the baseline regression if collapsed fisheries are included in the analysis.

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

The empirical strategy assumes that the collapse of fisheries within Japan's waters 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' EEZs as a result of the Japanese collapse. This would violate the exclusion restrictions since the Japanese foreign fishing fleet's activity could raise the probability of a collapse in the exporting countries in the sample.

In practice, this is not a concern. First, increasing costs lead to the decline of the Japanese long distance fleet (Swartz et al., 2010). Currently, the Japanese long distance fleet's activity focuses on tuna or takes place in the EEZs of China, South Korea and Russia. Since neither tuna nor Japan's neighbours are included in the sample, the Japanese fleet's activities do not invalidate the instrument. Second, there is no evidence that Japanese fishing in distant waters increases as a result of a collapse in Japan, as shown in Table 15 in the Appendix.

Third, the results do not change once landings by the Japanese foreign fishing fleet off the exporting country's waters are controlled for. The control variable "Jap. catch_{ikt}" measures catch of species i by Japanese vessels (in tonnes) in year t in FAO fishing areas adjacent to exporting country k's borders. The activity of Japanese vessels is measured using data from the FAO's Global Capture Production Database (accessed through FishStat J). The FAO's Global Capture Production Database contains information on a country's vessels' catch by year, species and FAO fishing area.[36] Controlling for "Jap. catch_{ikt}" yields a coefficient estimate of 0.114 for exports. This is almost identical to the coefficient estimate in the baseline

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[36] The 19 FAO fishing areas (see map here: http://www.fao.org/fishery/area/search/en) are different from EEZs and include the high seas as well.

Table 8: No violation of instrument exogeneity

	(1)	(2)	(3)	(4)	(5)
	Long distance	Sample excludes observations from			Lagged
	fleet catch	Early collapse	U.S., Canada	West Pacific	IV
L.Ln(Exports)	0.114**	0.122**	0.112***	0.116**	0.130**
	(0.046)	(0.061)	(0.037)	(0.047)	(0.053)
L.Jap. catch	-0.001***				
	(0.000)				
IV	L.Col. Jap.	L.Col. Jap.	L.Col. Jap.	L.Col. Jap.	L2.Col. Jap.
1st stage F-Stat	10.751	11.563	16.031	11.110	9.290
A.-R. p-value	0.003	0.011	0.002	0.005	0
No. of clusters	107	104	92	105	104
Observations	8876	8384	8130	8355	8712

Dependent variable: Collapsed. Column 1 controls for catch by the Japanese long distance fleet in the FAO fishing area adjacent to the exporting country. Column 2 excludes all country-species-combinations from the sample in which the first reported collapse of fishery i in the exporting country k precedes the first reported collapse of fish species i in Japan. Column 3: Sample excludes observations from U.S. and Canada. Column 4: Sample excludes observations from the Western Pacific. Column 5 uses the collapse in Japan in period $t-2$ as an instrument instead of the collapse in period $t-1$. Standard errors (clustered at the species level) in parentheses. The p-value of the Anderson and Rubin (1949) test (A.-R. p-value) provides weak instrument robust inference. * p<0.1, ** p<0.05, *** p<0.01

regression.

7.2 A collapse in Japan is not driven by Japanese exports

The exclusion restrictions would also be violated if a species' collapse in Japan was the result of the same species' collapse in the exporting country. This is unlikely to drive the results for several reasons. First, fisheries are only observed in the dataset up to the year in which they collapse. Therefore, the estimates are not affected by events that happen as a result of a collapse in the exporting country unless the fishery recovers and reappears in the dataset.[37] Second, Figure 5 shows that Japan exports a small fraction of its landings and is a net importer throughout the sample period. Hence, it is unlikely that exports caused the collapse of fisheries within Japan's waters.

Third, it is reasonable to think of Japan as the first (or at least an early link) in a potential chain of serial resource collapse. In the entire sample of Sea Around Us

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[37] Section C.8 shows that there is no significant difference in the effect of exports across fisheries that have previously collapsed and other fisheries.

Catch data (not all of which are used in the analysis due to a lack of export data), 113 fish species collapsed in Japan prior to 2006. For 30 percent of those species, Japan was the first country worldwide to report a collapse of the respective species.

The baseline results follow through in a sample that excludes all country-species-combinations in which the first reported collapse of fish species i in the exporting country k precedes the first reported collapse of fish species i in Japan (see Column 2 of Table 8).

7.3 Environmental factors do not violate instrument exogeneity

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

To further reduce the probability of ecosystem spillovers and shared environmental shocks, the US and Canada are excluded from the sample. The coefficient estimate of 0.112 in Column 3 of Table 8 is very similar to the baseline result and indicates that the findings in this paper are not driven by common shocks between Japan and the US or Canada. Moreover, there is no evidence of biased coefficient estimates due to common shocks affecting Japan and countries in the Western Pacific. Column 4 of Table 8 shows that the results follow through in a sample that excludes countries in the Western Pacific (FAO fishing area 71).

The probability of ecosystem linkages and shared shocks between Japan and the exporting country can be reduced further using the collapse in Japan in year t-2 as an instrumental variable. This yields a marginally higher coefficient estimate of 0.13 than the baseline regression (see Column 5 of Table 8).

8 Conclusion

This paper investigates the causal effect of fisheries exports on the collapse of fisheries. The analysis is based on a very detailed global panel dataset with variation at the country-species-year level. Due to the endogeneity of exports, the collapse of fisheries within Japan's Exclusive Economic Zone is used as a novel instrument for exports of fishery products.

The paper finds that exports have a large negative impact on fisheries' viabilities. An increase in logged exports by one standard deviation raises the probability of a collapse in the following year by 31 percentage points.

In light of the results presented in this paper, trade liberalization should be accompanied by the implementation of fisheries management in exporting countries. Sustainable management is particularly important for developing countries, which export half of the global export value (FAO, 2016b). In those countries, exports of fishery products are an important source of foreign exchange earnings, income and employment. To guarantee long-term benefits from fisheries and avoid fisheries collapse, exporters of fisheries products should ensure sustainable management.

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A Online Theory Appendix

A.1 Autarky equilibrium

This section describes the demand side of the economy as well as the autarky equilibrium. In autarky, the country neither imports nor exports fish or manufacturing products. All of the country's production is consumed domestically.

There are L_T consumers in the economy since each worker spends all of his or her income on consumption. Each 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

$$u = h^{\beta} m^{(1-\beta)}. \tag{9}$$

At time t, each consumer maximizes consumption subject to a budget constraint

$$ph + m = w \tag{10}$$

where w is the worker's wage income. The price of the manufactured product is normalized to 1 and p is the price of fish. Maximizing utility (9) subject to the budget constraint (10) yields the individual demand for fish $h = \beta w/p$ and manufactured goods $m = (1-\beta)w$. Multiplying individual demand by the number of workers in the economy L_T yields the aggregate demand for fishery products

$$H^C = hL_T = \frac{\beta w L_T}{p}. \tag{11}$$

Substituting the price from Equation 4 into the aggregate demand for fish from Equation 11 pins down the short run equilibrium supply of fish as a function of the stock size

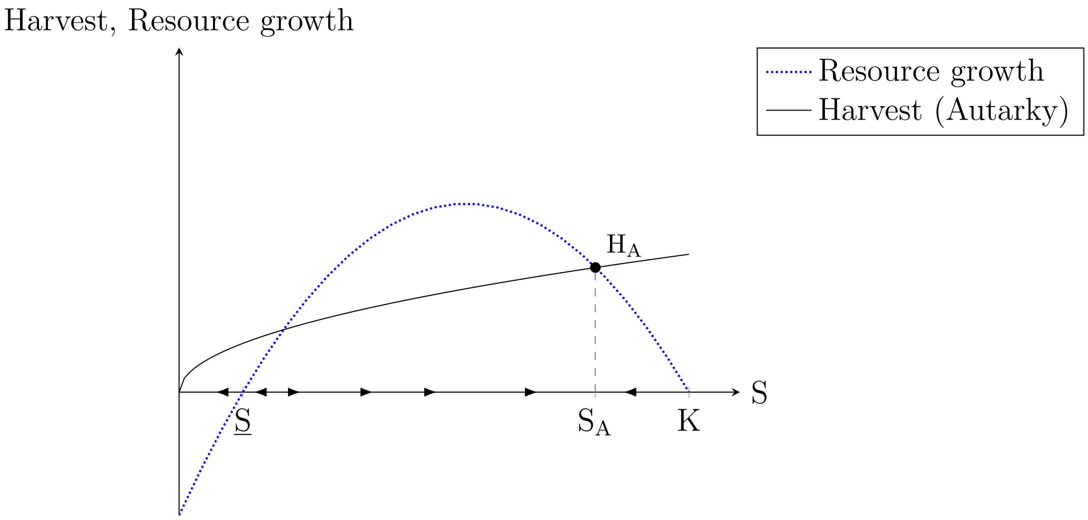
$$H = \beta L_T \alpha S^{\tau}. \tag{12}$$

Equation 12 shows that, in the short-run equilibrium, a fraction β of workers are 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 (see Figure 9) with a stable steady state resource stock of S_A.[38] The autarky price p_A is determined endogenously based on Equation 4 as $p_A = 1/(\alpha S_A^{\tau})$.

Note that the fishery can collapse even in the absence of trade if the parameters of the model are such that $G(S)$ and H do not intersect for any positive stock size.

Figure 9: Resource dynamics and catch function



A.2 Specialized steady state

A specialized steady state is possible at high world market prices, when the specialized catch function and the resource growth function intersect. Let us define S_z as the stable steady state stock at which the specialized catch function equals resource growth and define $p_z = 1/(\alpha S_z^{\tau})$. If the resource price increases from $p_1 < p_z$ to $p_2 > p_z$, the economy instantly specializes in fishing and catch surges. The stock shrinks gradually due to the intense fishing pressure. Once the stock has declined 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 be depleted, even at high resource prices. The economy remains specialized at S_z, since the marginal value product of labour in fishing exceeds the marginal value product of labour in manufacturing at $p_2 > p_z$.

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[38] Mathematically, the steady state resource stock is described by the following equation: $\beta L_T \alpha S_A^{\tau} = r\,(S_A - \underline{S})\left(1 - \frac{S_A}{K}\right)$.

If the small open economy is initially a specialized steady state with $p_1 \geq p_z$, an exogenous increase in the world market price to p_2 would not affect catch, exports or stocks. All of the workers are already employed in fishing and the sector cannot attract additional labour to raise catch. The steady state equilibrium is not affected by an increase in the price from p_1 to p_2.

B Online Data Appendix

This section describes the dataset in detail. Table 9 provides an overview of all the variables, the data source used to construct the respective variables and the time frame during which those variables are available in the analysis dataset. Furthermore, it indicates where the variable is used in the paper.

B.1 Sea Around Us Catch Database

The collapse of Japanese Fisheries is inferred based on catch data from the Sea Around Us Catch Database. This database shows how much of each species was caught within a country's EEZ in a particular year. The Sea Around US Catch Database maps catch to a country's EEZ irrespective of the flag of the fishing vessel that caught the fish within the country's EEZ. The dataset used in this paper covers the years 1950 to 2006.[39]

To construct the Sea Around Us Catch Database, Watson et al. (2004) use FAO catch data (see Section B.6 and B.7) and map them to 30 min spatial grid cells using auxiliary information about species' distribution and fishing access agreements. The spatial distribution of species is useful in mapping catch to spatial grid cells, since species can only be caught where they occur. Moreover, countries can only fish within their own 200nm Exclusive Economics Zones or on the high seas, unless they have a fishing access agreement with another country. Therefore, Watson et al. (2004) also use data on fishing access agreements for specific target species to map catch for vessels flying a particular country's flag to grid cells in another country's EEZ. Once catch has been allocated to spatial grid cells, it can be aggregated to the level of the EEZ to show how much of each species was caught within a country's EEZ in a particular year. The construction of the Sea Around Us Catch Database is described in more detail in Watson et al. (2004).

B.2 Fisheries collapse

The collapse of a fishery is defined based on catch data from the Sea Around Us Catch Database. This paper uses a common approach (see e.g. Worm et al., 2006;

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

Table 9: Variables and data sources

Variable	**Data source**	**Available**	**Used in section**
Catch	Sea Around Us	1950-2006	Section 5.1
Collapse	Sea Around Us	1950-2006	Most sections
Collapse in Japan	Sea Around Us	1950-2006	Most sections
Previously collapsed	Sea Around Us	1950-2006	Most sections
Col. J. Family	Sea Around Us and ASFIS List of Species for Fishery Statistic Purposes	1950-2006	Section C.2
Species level export quantity	FAO Fisheries Commodities Production and Trade Statistics	1976-2006	Most sections
Maximum historical exports		1976-2006	Section 6
Years since max. exports		1976-2006	Section 6
Net exports		1976-2006	Section C.6
Export price		1976-2006	Section 5.1
Ex-vessel price	Swartz et al. (2012)	1950-2006	Sections 5.1, 5.4 and 6.2
Catch share data	EDF catch share database	1950-2006	Section 5.3
Biomass data	RAM Legacy Stock Assessment Database and Costello et al. (2016)	1950-2012	Section 6.2 and Section 8
Jap. Landings$_{ikt}$	FAO FishStat J	1950-2006	Section 7.1
Long distance total catch	FAO FishStat J	1950-2006	Appendix Table 15 (discussed in Section 7.1)
Distance	CEPII GeoDist Database	Not applicable	Section C.1
Aquaculture	FAO Fishstat J	1984-2006	Section C.7
Food Balance Sheet Data	FAO Food Balance Sheets	1961-2020	Figure 5

Costello et al., 2008) and defines a fishery as collapsed if catch from the fishery is below 10 percent of the maximum historical catch recorded since 1950. Hence, Collapsed_{ikt} takes the value of 1 if catch of fish species i in country k's EEZ is less than 10% of the maximum historical catch of species i within country k's EEZ recorded between 1950 and year t. Species are defined at the level of the 3-alpha code in the ASFIS List of Species for Fishery Statistics Purposes (FAO, 2021a).

Collapse in Japan's EEZ. The instrument, Col. Japan_{it}, is a dummy variable that takes the value of 1 if catch of fish species i within Japan's EEZ Japan t is less than 10% of the maximum historical catch of species i recorded between 1950 and year t with Japan's EEZ. The analysis dataset contains species that are not caught by Japan. When Japan does not report catch statistics for a particular species, the instrument takes a value of 0 for that species throughout the sample period.

Previously collapsed. The control variable "Prev. Collapsed" takes a value of 1 if the fishery ik (defined at the country-species-level) has collapsed in the past.

The variable **Col. J. Family**$_{it}$ is used as an instrument in Section C.2.The variable takes a value of 1 for species i in year t if species i is in the same family as a species j which is collapsed in Japan in year t. The variable only takes a value of 1 if species i itself is not collapsed. It takes a value of zero for the collapsed species j. The family a species belongs to is given by the variable “Family” in the ASFIS List of Species for Fishery Statistics Purposes (FAO, 2021a). Families in the sample include Gadidae (Cods), Pleuronectidae (Righteye Flounders), Sepiidae (Cuttlefishes).

B.3 Exports

Fisheries trade data at the country-commodity-year level are from the FAO Fisheries Commodities Production and Trade Statistics. The trade data are matched with catch data from the Sea Around Us Catch Database at the country-species-year level.

The next few paragraphs describe how the trade data, which are reported at the commodity level, were matched to the species level catch data. Table 10 provides some examples for fisheries trade commodities and shows two important features. First, it shows that the FAO trade data provide information on the way the fish is processed. For the purpose of our analysis, it does not matter whether the fish is fresh, frozen or prepared. Therefore, the export quantities at the species level are

Table 10: Examples of fisheries trade commodities

Atlantic cod, fresh or chilled
Atlantic cod, frozen
Atlantic cod, meat, frozen
European plaice, fresh or chilled
European plaice, frozen
Mussel meat nei, frozen
Mussel meat, prepared or preserved
Mussels nei, other than live, fresh or chilled
Mussels, live, fresh or chilled, nei

calculated as the total weight of the fish over all the different ways in which the fish is processed. Exports of cod, for example, are the unweighted sum of exports of fresh or chilled cod, frozen cod as well as frozen cod meat. Some species are also exported in dried form. Due to a lack of systematic conversion rates for all fish species, it is not possible to convert the dry weight to wet weight. Hence, dry weight is treated the same way as wet weight.

Table 10 also shows that exports are recorded at the species level for some species like Atlantic cod and European plaice. For other species, such as mussels, the trade statistics are reported in more aggregate categories. The category “Mussels” includes a whole range of taxonomic species and the catch data would generally provide information at a more disaggregate level (i.e. the species level). Since it is not possible to know which of the mussel species in the catch data are traded and which ones are not traded, it is impossible to know whether an increase in exports of “Mussels” raises catch, and hence the probability of collapse, of one specific species of mussel. Therefore, the data on aggregate categories like “Mussels” are not used in the analysis.

Species level exports in the paper are measured in metric tonnes. The main specification of the paper uses the natural logarithm of this variable.

Maximum historical exports. Fishery ik's maximum historical exports recorded up to year t are defined such that fishery ik's maximum historical exports increase over time as the fishery's exports increase. Once the fishery's exports have reached a peak, the variable stays constant. The variable is measured in metric tonnes.

Years since max. exports. This variable takes a value of zero while the fishery is developing and positive values once exports have peaked and are in decline.

Net exports are defined as exports minus imports at the country-species-year level measured in metric tonnes.

B.4 Ex-vessel price data

Ex-vessel prices are from Swartz et al. (2012), who collected a global ex-vessel fish price dataset combining publicly available fisheries statistics from national and intergovernmental agencies and information from the grey literature. The dataset shared with me covers 19,000 data points at the country-species-level. Swartz et al. (2012) combine these price data with the Sea Around Us Catch Database and estimate all missing prices for 260,000 observations covering 193 countries and almost 1500 species groups from 1950 to 2006.

The estimation assumes that prices are determined by the flag of the fishing vessel, taxonomy and the year. Swartz et al. (2012) use existing ex-vessel price data to compute a species' annual average price (they call it the international price) and adjust this international price to domestic prices using a measure of the country's purchasing power parity from the Penn World Tables. Average prices were estimated independently for each year. This approach yields a country-species-year specific price.

Estimation of a species' average price is only possible if ex-vessel price data are available for the species in at least one country. When no price data were available, Swartz et al. (2012) imputed prices from the same genus or family and the estimation of missing values was carried out based on these imputed data.

B.5 Export prices

It is also possible to calculate export prices based on trade data. The FAO Fisheries Commodities Production and Trade Statistics report both export values and export quantities for all product commodities. This means that export prices at the species level can be constructed as the ratio of export values and export quantities for all species for which these data are available. The export quantities at the species level are calculated as described in Section B.3. The same matching and aggregation method is used to calculate export values at the species level.

B.6 Catch by the Japanese long-distance fleet

The activity of the Japanese long-distance fleet is measured using data from the FAO's Global Capture Production Database (accessed through FishStat J). The FAO's Global Capture Production Database contains information on a country's vessels' catch by year, species and FAO fishing area. The FAO divides the world into 19 fishing areas and a map of the 19 FAO fishing areas is available at http://www.fao.org/fishery/area/search/en. Any catch by Japanese vessels outside of the FAO fishing area surrounding Japan (fishing area 61) is considered catch by the Japanese long-distance fleet in the context of this paper.

Long distance total catch$_{it}$ is measured in tonnes and represents catch by Japanese vessels of species i in year t in all FAO fishing areas except the fishing area surrounding Japan (i.e. in all fishing areas except fishing area 61). The variable is constructed based on data from the FAO's Global Capture Production Database.

Jap. Landings$_{ikt}$ measures catch of species i by Japanese vessels (in 1000 metric tonnes) in year t in FAO fishing area(s) adjacent to country k's borders, where country k is the exporting country. This variable is used as a control variable in Section 7.1.

B.7 Difference between FAO Global Capture data and Sea Around Us Catch data

The activity of the Japanese fleet is best measured using data from the FAO's Global Capture Production Database (accessed through FishStat J). The FAO FishStat J Database links a vessel's catch to a particular country based on the flag of the fishing vessel, i.e. the catch by a vessel with a Japanese flag is categorized as Japanese catch irrespective of where it is caught. The data in FAO FishStat J also have a spatial dimension and indicate in which of the 19 FAO fishing areas the fish was caught. The fishing areas are different from EEZs and include the high seas as well.

In contrast, the Sea Around Us Catch Database maps catch to the country's EEZ, irrespective of the flag of the vessel which caught the fish. Catch in the Japanese EEZ could be caught by Japanese vessels or vessels with a different country's flag with access to Japanese waters due to a fishing access agreement. The Sea Around Us Catch Database is more suitable for measuring the collapse of stocks within a country's EEZ than the FAO database.

B.8 Data on catch share programs

The analysis makes use of data on catch share programs from the Environmental Defense Fund (EDF). The dataset contains information on catch share programs in all countries at the species-level. The author contacted the respective fisheries management authorities and used information from government websites and scientific articles to complete missing information on the year in which a catch share program was adopted.

A few countries have different regulations for different segments of their fishing fleet. There are a few instances in which the catch share program for a particular species is introduced in different years for different fleet segments. A particular species is recorded as managed as soon as a country adopts a catch share program for one particular segment of its fleet that targets the respective species. This assumption is unlikely to have a large impact on the results since the problem is not very prevalent.

B.9 Distance

Distance is measured as the great circle distance (in 1000km) between the cities with the largest population in each country using data from the CEPII GeoDist database (Mayer and Zignago, 2011).

B.10 Biomass

This paper uses biomass data from Costello et al. (2016). The dataset contains biomass data from the RAM legacy stock assessment database (Ricard et al., 2012) where available and supplements them with estimates of stock biomass from Costello et al. (2016).

Costello et al. (2016) use a two-step approach to estimate biomass for unassessed fisheries. First, they use a Panel Regression Model similar to Costello et al. (2012) in which B/B_{MSY} is modelled as a function of a number of variables capturing harvest history (e.g. age of the fishery, maximum harvest, catch/maximum harvest and others) and life-history parameters (e.g. age at maturity, maximum length and others). The parameters of this empirical model are estimated using data from the

RAM legacy stock assessment database. The coefficient estimates from the panel regression model, data on harvest history and the life-history parameters are then used to predict B/B_{MSY} for unassessed fisheries. This implicitly assumes that the relationship between B/B_{MSY}, harvest history and life-history parameter is the same for unassessed stock and assessed stocks.

In a second step, predictions of $\mathrm{B}/\mathrm{B}_{MSY}$ from the panel regression model are modified to reflect additional information on the biology of the species. This is done using the catch-MSY approach developed by Martell and Froese (2013). The catch-MSY method uses priors on species growth rates and carrying capacity as well as priors on stock status (where Costello et al. (2016) use the B/B_{MSY} priors from the panel regression model). Costello et al. (2016) then apply a production model and catch history data to the priors rejecting any runs that either result in biomass of less than 0 or result in stock status outside the prior bounds.

This paper makes use of Costello et al. (2016)'s UnlumpedProjectionData.csv which allocate results for multinational stocks to participating countries according to their historical participation in the fishery. However, high-seas and highly migratory fish species are not included in the analysis to make the results comparable across sections of the paper.

For the purpose of the analysis conducted in this paper, the data were aggregated to the country-species-year level if there were several stocks per species within a country. Biomass is the sum of the biomass for all stocks of one species within a country.

Further details on the biomass data are available in Costello et al. (2016) and the accompanying supplemental material.

B.11 Aquaculture data

Aquaculture data at the species level are from FAO Fishstat J. Those data are matched with the catch statistics at the country-species level using country codes and 3-alpha codes from the ASFIS List of Species for Fishery Statistic Purposes (FAO, 2021b). Not all species are suitable for aquaculture production. It is assumed that aquaculture production is zero if FishStat J does not report aquaculture production of a particular species.

B.12 Food balance sheet data

Figure 5 uses data from the FAO Food balance sheets. To be precise, Figure 5 is based on the 4 variables listed below. The FAO food balance sheets measure those variables by year, country and type of marine animal (i.e. Cephalopod, Crustacean, Demersal Fish, Freshwater Fish, Marine Fish etc.). The data shown in Figure 5 are aggregates over all of those categories except freshwater fish, since data on freshwater fish are not used in the analysis.

Catch (i.e. Production): “Production” of fish measures the “live weight for fish items (i.e. the actual ex-water weight at the time of the catch).” The variable is measured in 1000 metric tonnes

Domestic Supply. The FAO food balance sheets define domestic supply as production-exports+imports+stock changes. Stock variation "comprises changes in government stocks, in stocks with manufacturers, importers, exporters, other wholesale and retail merchants, transport and storage enterprises and in stocks on farms" (FAO, 2021b). Reported stock variation is zero for most years and most categories of fisheries products.

Export quantity is measured in 1000 metric tonnes.

Import quantity is measured in 1000 metric tonnes.

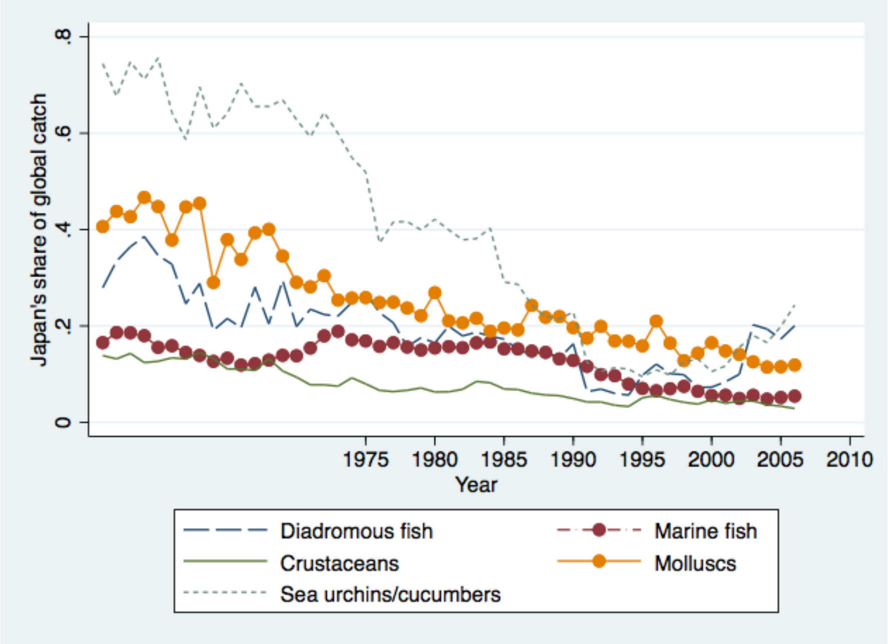
C Online Empirical Appendix

Table 11: Fisheries collapse by taxa

	Observations	Collapse in exporting countries	Collapse in Japan
Abalones, winkles, conchs	62	3	2
Clams, cockles, arkshells	2	0	0
Cods, hakes, haddocks	2174	109	29
Crabs, sea-spiders	129	1	3
Flounders, halibuts, soles	1606	52	23
Herrings, sardines, anchovies	1031	59	5
King crabs, squat-lobsters	92	11	0
Lobsters, spiny-rock lobsters	572	20	0
Miscellaneous coastal fishes	255	4	18
Miscellaneous demersal fishes	581	38	27
Miscellaneous pelagic fishes	532	21	17
Oysters	65	6	0
Salmons, trouts, smelts	401	35	5
Scallops, pectens	141	8	0
Sea-urchins and other echinoderms	207	4	0
Shads	25	0	0
Sharks, rays, chimaeras	95	1	9
Shrimps, prawns	181	13	0
Squids, cuttlefishes, octopuses	725	28	14

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

Figure 10: Japan's share of global catch by species category



Author's calculations based on data from the Sea Around Us Catch Database.

Table 12: Correlation between collapse in Japan and Japanese imports

	(1) Japanese Imports	(2) Ln(Japanese Imports)
Collapsed	9651.469	0.029
	(7024.139)	(0.199)
Year FE	Yes	Yes
Species FE	Yes	Yes
No. of clusters	18	18
Observations	321	295

This table shows the conditional correlation between the collapse in Japan and Japanese imports. The dependent variable is the quantity of Japanese imports of species i in year t. The regressor is the collapse of the species in Japan's EEZ. Year fixed effects capture time trends in imports that are constant across species. The regression also includes species fixed effects. The sample spans the years 1976-2006 and only contains Japanese fisheries. High seas and highly migratory fish species are not in the sample. Standard errors are clustered at the species level and given in parentheses.

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

Table 13: Robustness: Effect of exports on catch share fisheries

	(1)	(2)	(3)
L.Ln(Export quantity)	0.112**	0.156	0.118
	(0.046)	(0.100)	(0.102)
L. ln(Exports) × L.Catch share	0.008	0.083	-0.042
	(0.033)	(0.086)	(0.045)
L.Catch share	-0.132	-0.800	0.336
	(0.283)	(0.768)	(0.370)
Controls	✓	✓	✓
Region-Year FE	✓		✓
Country FE	✓		
Species FE	✓	✓	
Country-Year FE		✓	
Country-Species FE			✓
1st stage F-Stat	10.097	3.092	4.068
Anderson-R. p-value	0.006	0.132	0.051
No. of clusters	107	107	106
Observations	8876	8876	8819

The dependent variable is Collapsed_{ikt}. Collapse Japan_{it-1} and Collapse $\text{Japan}_{it-1}\times$ Catch share_{ikt-1} are used as instruments for $\ln(\text{Exports})_{ikt-1}$ and $\ln(\text{Exports})_{ikt-1}\times$ Catch share_{ikt-1}. The p-value of the Anderson and Rubin (1949) test (Anderson-R. p-value) provides weak instrument robust inference. Standard errors (clustered at the species level) in parentheses.

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

Table 14: Catch share adoption is exogenous

	(1) Catch share program_{ikt}
Collapsed_{ikt-1}	-0.0009
	(0.0058)
Country-species FE, Year FE	Yes
Observations	7946

This table shows the relationship between the collapse of a fishery ik in year $t-1$ and the government's decision to introduce a catch share program for this fishery in year t. In the dataset used for this analysis, a fishery is observed up to the year in which it introduces a catch share program. Fisheries that do not introduce catch share programs are observed until the end of the sample period. Standard errors (clustered at the country-species level) in parentheses. * p<0.1, ** p<0.05, *** p<0.01

Table 15: Catch by the Japanese long distance fleet does not increase

	(1) Long distance total catch
Col. Japan	-607.729
	(1227.946)
Observations	1199

The dependent variable Long distance total catch$_{it}$ measures the catch of species i in year t by Japanese vessels in all FAO fishing areas except the fishing area surrounding Japan. The variable is measured in tonnes and is constructed based on data from the FAO's Global Capture Production Database accessed through FishStatJ. Long distance total catch$_{it}$ is regressed on the collapse of species i in Japan in year t, on year fixed effects and species fixed effects. The sample does not include highly migratory and high seas fish stocks. Standard errors (clustered at the species level) in parentheses.

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

C.1 Exporter's distance from Japan

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

Exports are likely to react less to the collapse of a Japanese fishery the further the country is from Japan.[40] Therefore, the instrumental variable "Collapse Japan" is interacted with a measure for the distance between Japan and the exporting country. Distance is measured as the great circle distance (in 1000km) between the cities with the largest population in each country using data from the CEPII GeoDist database (Mayer and Zignago, 2011).

With this instrument, an increase in exports by one percent is estimated to raise the probability of a collapse by 0.12 percentage points. This coefficient estimate, which is displayed in Column 1 of Table 16, is only slightly higher than the coefficient estimate in the baseline regression.

C.2 Substitution effects

In the case of substitution across species, the estimated effect of exports has to be considered a lower bound of the true effect. In other words, the effect of exports on the collapse of species would be even stronger than this paper's results suggest if there were strong substitution effects across species. This section explains how substitution across species would affect the results. It also shows that the results are not biased due to substitution across species within the same family. However, it is not possible to rule out biases resulting from more complex substitution patterns.

Substitution effects may occur since the collapse of a Japanese fishery is associated with an increase in the price of the collapsed species. In response to this increase in price, consumers may shift their expenditure to a close substitute. This, in turn, could raise the price of, and export demand for, the substitute, and induce fishermen to harvest more of the substitute. The resulting increase in the probability of a collapse of the substitute would bias the coefficient estimate downward.

It is possible to investigate substitution across species within the same family. 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

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

Table 16: Alternative instruments and substitution effects

	(1) IV distance	(2) Substitution
L.Ln(Export quantity)	0.123**	0.109**
	(0.062)	(0.046)
FEs and controls	Yes	Yes
IV 1	Col. Japan*distance	L.Col. Japan
IV 2	-	L.Col. J. Family
1st stage F-Stat.	5.845	5.225
Anderson-R. p-value	0.008	0.013
No. of clusters	107	107
Observations	8872	8876

Dependent variable: Collapsed_{ikt}. Column 1 uses a different instrument: The collapse of the fishery in Japan is interacted with the exporter's distance from Japan. Column 2 uses a Japanese collapse in the same species family as a second instrument to assess substitution on the demand side. Standard errors (clustered at the species level) in parentheses.
* p<0.1, ** p<0.05, *** p<0.01

as a second instrument to assess whether export demand for a species increases as a result of a collapse of another species within the same family. The variable takes a value of 1 for species i in year t if species i is in the same family as species j and species j is collapsed in Japan in year t. The variable only takes a value of 1 if species i itself is not collapsed. It takes a value of zero for the collapsed species j. The family a species belongs to is given by the variable "Family" in the ASFIS List of Species for Fishery Statistics Purposes (FAO, 2021a). Families in the sample include Gadidae (Cods), Pleuronectidae (Righteye Flounders), Sepiidae (Cuttlefishes). A positive and statistically significant coefficient estimate for the variable "Col. J. Family_{it}" in the first stage regression would indicate that export demand for a species increases when another species in the family collapses in Japan.

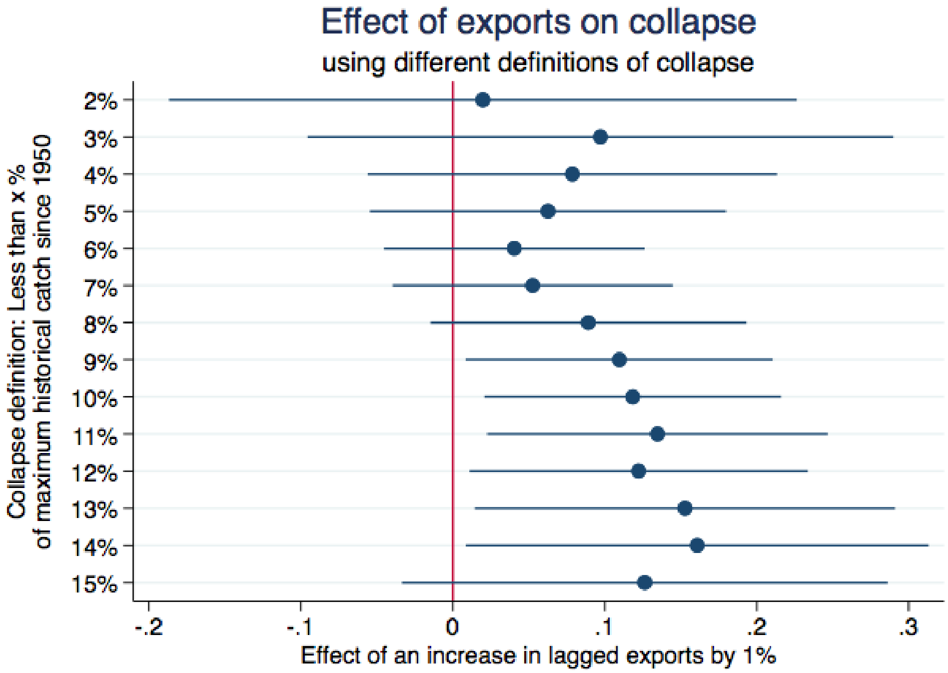
There is no evidence of substitution within family. In the first stage regression, the coefficient estimate for "Col. J. Family_{it}" is not significant. This indicates that there is no increase in export demand as a result of a collapse of another species in the same family. Moreover, the results in the second stage regression are not affected by the introduction of this second instrument, indicating that the results are not biased downward due to substitution within family. Column 2 of Table 16 shows that an increase in exports by one percent is estimated to raise the probability of a fishery's collapse by 0.11 percentage points. This is very similar to the findings in the baseline regression. It is reassuring that the test for overidentifying restrictions suggests that the instruments are valid.

While the analysis presented here does not find evidence of substitution within family or an associated bias in the coefficient estimate, it is possible that there are more complex patterns of substitution across species which would not be captured by this analysis. In that case, the coefficient estimate for the effect of increase in exports has to be considered a lower bound of the true effect.

C.3 Measurement error in fisheries collapse

Even though the collapse of fisheries is inferred based on catch statistics, measurement error in the dependent variable does not seem to bias the results.

Figure 11: Effect of exports on collapse using different definitions of collapse



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

C.3.1 Different definition of fisheries collapse

The results are largely robust to changing the definition of fisheries collapse. This is shown by Figure 11 which defines collapse as having occurred with different percentages of the maximum historical catch since 1950. The figure displays the estimated effect of a one percent increase in lagged exports on the probability of a collapse for separate regressions each using a different definition of fisheries collapse. A fishery is defined as collapsed if catch is less than x percent of the maximum historical catch recorded since 1950, where all cut-offs, x, between 2% and 15% are considered. The coefficient estimates are presented with 95% confidence intervals.

The results point towards a statistically significant increase (at the 10%) level in the probability of a collapse, as long as the cut-off is between 8% and 14%. The coefficient estimates are statistically significant using weak-instrument robust inference for cut-offs of 4%, 15% and 16%. For all other cut-offs, the coefficient estimates are positive but not significant. However, particularly for small cut-offs, the coefficient estimates may be biased downwards since the instrument is weak.[41]

C.3.2 Fisheries collapse and the introduction of fisheries management

Measurement error in fisheries collapse could result from the introduction of strict fisheries management. The fishery may be falsely defined as collapsed if a government closes the fishery temporarily or sets a catch limit of less than 10% of the maximum historical catch. This would only bias the results if the resulting measurement error in fisheries collapse was systematically related to the instrumental variable. However, there is no reason to believe that the introduction of strict catch limits outside of Japan is related to the collapse of the same species in Japan.

Moreover, measurement error resulting from the introduction of catch limits does not appear prevalent in the analysis sample. To the best of my knowledge, the catch

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[41] 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 in period t. Therefore, the collapse in Japan raises the probability of a collapse in the exporting country. However, it is not generally the case that an exogenous increase in the price in period $t-1$ leads to a smaller catch in period t. A country which is in a diversified steady state in period $t-2$ and specializes in fisheries in period $t-1$ does not necessarily catch less in period t than in period $t-2$ if it remains specialized in period t.

share dataset is the only comprehensive global dataset on fisheries management, and there are no global datasets on other fisheries management tools. Therefore, the analysis focuses on the introduction of catch share programs. There are only three fisheries in the sample for which the adoption of a catch share program coincides with the collapse of the fishery. The collapse might be mismeasured in those three instances if the reduction in catch is due to the new regulatory measures. However, stock data, which are available for one of those fisheries, suggest that the stock had actually declined drastically. The results are similar to the baseline results if the above-mentioned three fisheries are excluded from the analysis sample.

C.4 Different fixed effects

The results follow through with different sets of fixed effects, as shown in Table 17. Column 1 shows results with year fixed effects, country fixed effects and species fixed effects. Column 2 presents results with region time trends, species fixed effects and country fixed effects and Column 3 shows results with species fixed effects and country-year fixed effects. Column 4 represents results with year fixed effects and country-species fixed effects. The coefficient estimates are larger than in the baseline regression and all of them are statistically significant using weak instrument robust inference. If anything, the baseline regression underestimated the true effect size. Column 5 shows results with FAO area-year fixed effects. The FAO divides the world's oceans into 19 distinct areas. The regression includes one dummy variable for all FAO-area and year combinations. The coefficient estimate of 0.13 is almost identical to the estimated effect in the baseline regression.

C.5 The distribution of exports is skewed

This section shows that distribution of the export quantity is highly skewed and that outliers drive the results when the level of exports is used as a regressor.

The dispersion of the export quantity is highly skewed. The majority of fisheries have small exports (the sample median is 850 MT), but there are a few outliers with significantly higher export quantities exceeding 100,000 MT in the sample. This is also shown in the histogram in Figure 12.

These outliers have a strong effect on the results in a regression with the level of exports as a regressor as demonstrated in Table 18. The results in Column 1 of Table 18 are based on the same sample as the baseline regression. Column

Table 17: Different fixed effects

	(1)	(2)	(3)	(4)	(5)
L.Exports	0.134**	0.149**	0.150	0.171	0.126*
	(0.056)	(0.064)	(0.093)	(0.156)	(0.071)
Year FE	✓			✓	
Region time trend		✓			
FAO area-year FE					✓
Species FE	✓	✓	✓		✓
Country FE	✓	✓			✓
Country-year FE			✓		
Country-species FE				✓	
Controls	Yes	Yes	Yes	Yes	Yes
1st stage F-Stat	9.424	7.976	3.948	2.193	6.679
Anderson-R. p-value	0.003	0.001	0.052	0.047	0.030
No. of clusters	107	107	107	106	107
Observations	8876	8876	8880	8819	8876

Dependent variable: Collapse$_{ikt}$. Standard errors (clustered at the species level) in parentheses. The p-value of the Anderson and Rubin (1949) test (Anderson-R. p-value) provides weak instrument robust inference.

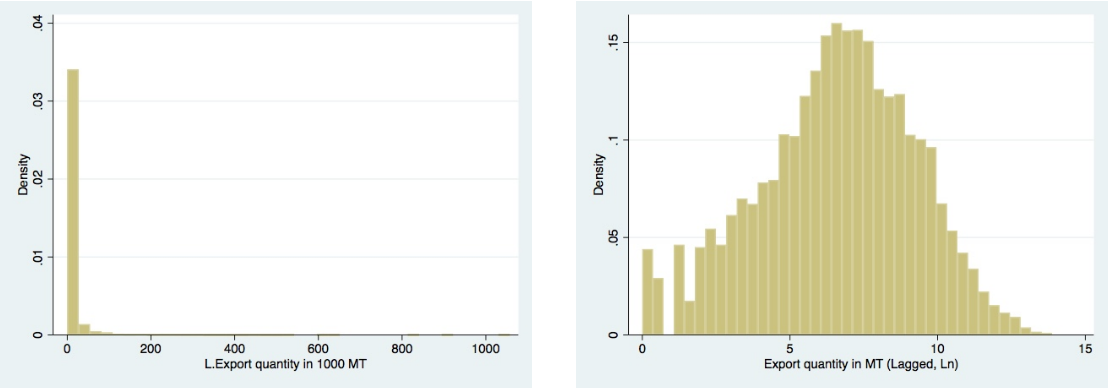
* p<0.1, ** p<0.05, *** p<0.01

1 suggests that an increase in exports by 1000 MT reduces the probability of a collapse by 0.6 percentage points. This result, however, is entirely driven by outliers with extremely high export quantities. When those outliers are removed, the results show that an increase in exports raises the probability of a collapse. For the results shown in Column 2, outliers exceeding 100 times the median export quantity in the baseline sample were removed. The results in Column 3 remove a smaller set of observations with exports exceeding the 99th percentile of the export quantity in the baseline sample. The results in Columns 2 and 3 show that an increase in exports by 1000 MT raises the probability of collapse in the following year by 14.8 and 5.9 percentage points respectively. Both coefficient estimates are statistically significant using weak instrument robust inference.

C.6 Net exports

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

Figure 12: Histogram of export quantity and ln(export quantity)



The estimated effect of net exports on fisheries collapse is stronger than the effect of gross exports. The results in Column 1 of Table 19 suggest that an increase in net exports by one percent raises the probability of collapse in the following period by 0.22 percentage points. This is almost twice the effect size found in the baseline regression.

The long-term effect of net exports on the collapse of a fishery can be captured by the fishery's maximum historical net exports. Column 2 of Table 19 shows that an increase in maximum historical net exports by one percent raises the probability of a fishery's collapse by 0.11 percentage points. These findings indicate that net exports have a significant and large negative impact on the sustainability of fisheries.

C.7 Aquaculture

The possibility to harvest a species using aquaculture production seems to take pressure off wild-capture fisheries and dampen the effect of exports on the collapse of fisheries. There is tentative evidence that species that are suitable for aquaculture production are not depleted due to exports (see Column 3 of Table 19). Column 4 of Table 19 reveals that the results from the baseline regression follow through if fisheries which report positive aquaculture production are excluded from the sample. Data on aquaculture production are from FAO Fishstat J.

Table 18: Exports in levels

	(1)	(2)	(3)
Sample:	Baseline	Exports<85,000 MT	Exports<175,000 MT
L.Export quantity in 1000 MT	-0.006	0.148	0.059
	(0.005)	(0.506)	(0.164)
Controls	Yes	Yes	Yes
Fixed effects: γ_{rt}, γ_i, γ_k	Yes	Yes	Yes
1st stage F-Stat	1.190	0.088	0.122
Anderson-R. p-value	0.004	0.004	0.004
No. of clusters	107	107	107
Observations	8876	8660	8787

Dependent variable: Collapsed. Regressor: Export quantity (in 1000 MT). Column 1 uses the same sample as the baseline regression. Columns 2 and 3 remove outliers with exports exceeding 85,000 MT (100 times the sample median) and 175,000 MT (the 99th percentile). Standard errors (clustered at the species level) in parentheses. The p-value of the Anderson and Rubin (1949) test (Anderson-R. p-value) provides weak instrument robust inference.
* p<0.1, ** p<0.05, *** p<0.01

C.8 Heterogeneity analysis based on previous collapse

Fisheries that have collapsed in the past are not more likely to collapse when exports surge than other fisheries. This can be shown through an interaction term between exports and the dummy variable “Prev. Collapsed”, which equals 1 if the fishery has collapsed in the past. Given that exports are endogenous, the interaction term between exports and “Prev. Collapsed” is endogenous as well. Therefore, the collapse in Japan interacted with “Prev. Collapsed” is used as a second instrument.

The coefficient estimate for “L. ln(Exports) × Prev. collapsed” in Table 20 indicates that there is no significant difference in the effect of exports across fisheries that have previously collapsed and other fisheries.

C.9 Including collapsed fisheries in the analysis sample

Observations from collapsed fisheries are not used in the analysis, since they cannot tell us how an increase in exports leads to the collapse of the fishery. This section conducts a robustness test including observations from collapsed fisheries in the sample and finds that the estimated effect of exports on the probability of collapse is even higher than in the baseline regression.

In the first stage regression, the estimated effect of a collapse in Japan on exports

Table 19: Net exports

	(1) Collapsed	(2) Collapsed	(3) Collapsed	(4) Collapsed
Sample:	All	All	Aquaculture	No aquaculture
L.Ln(Net Exports)	0.222			
	(0.227)			
Ln(Max. Net Exp.)		0.112		
		(0.087)		
L.Exports			-0.087	0.115**
			(0.218)	(0.046)
Fixed effects and controls	Yes	Yes	Yes	Yes
1st stage F-Stat	1.212	2.605	1.613	10.329
Anderson-R. p-value	0.010	0.106	0.622	0.004
No. of clusters	104	108	13	106
Observations	5799	8306	334	8540

Column 1: The regressor *Net exports* is defined as Exports-Imports. Column 2: The regressor it the natural logarithm of maximum historical net exports. Column 3: Sample includes all fisheries (country-species combinations) for which the FAO reports positive aquaculture production quantities. Column 4: Sample includes all fisheries for which the FAO does not report aquaculture production. Standard errors (clustered at the species level) in parentheses. The p-value of the Anderson and Rubin (1949) test (Anderson-R. p-value) provides weak instrument robust inference. * p<0.1, ** p<0.05, *** p<0.01

in other countries is smaller when collapsed fisheries are included in the sample. Column 1 of Table 21 show an effect size of 0.15, which is less than the effect of 0.19 shown in Table 2. This is not surprising. If fisheries have collapsed in the exporting country, it is not possible to raise exports in response to an export demand shock originating from Japan.

The second-stage regression reveals that an increase in exports raises the probability of a collapse by 0.21 percentage points (see Column 2 of Table 21). The estimated effect is bigger than in the baseline regressions. The coefficient estimate is statistically significant based on weak instrument robust inference, which is necessary here because of the small first stage F-statistic.

Table 20: Heterogeneity analysis: Previous collapse

	(1) Collapse
L.Exports	0.120**
	(0.052)
L. ln(Exports) × Prev. collapsed	-0.007
	(0.029)
Prev. collapsed	0.193
	(0.211)
FEs and controls	Yes
IV 1	L.Col. Japan
IV 2	L.Col. Japan × Prev. collapsed
1st stage F-Stat.	12.628
Anderson-R. p-value	0.010
No. of clusters	107
Observations	8876

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. Prev. collapsed equals 1 if the fishery has collapsed in the past.

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

Table 21: Including collapsed fisheries in the sample

	(1) Exports	(2) Collapse
L.Col. Japan	0.146*	
	(0.077)	
L.Exports		0.209
		(0.176)
Controls	Yes	Yes
Fixed effects: γ_{rt}, γ_i, γ_k	Yes	Yes
1st stage F-Stat		3.643
Anderson-R. p-value		0.088
No. of clusters	109	109
Observations	10783	10783

The sample used here also includes collapsed fisheries. Column 1 shows the first stage regression and Column 2 shows the IV results. Standard errors (clustered at the species level) in parentheses. The p-value of the Anderson and Rubin (1949) test (Anderson-R. p-value) provides weak instrument robust inference.

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