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Honors Program

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The Effect of Increasing Sea Surface Temperature on Fishery Production: What countries are vulnerable?

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Abstract

As climate change is increasing the ocean temperatures, there will be changes to the components in our oceans that will affect fish dynamics, and further fishery production. This will pose serious problems for countries that are dependent on fishing for economic or nutritional reasons. Little research has been done analyzing the relationship between fishery production and sea surface temperature to establish whether the warming oceans are affecting the fishing industries. Thus, this paper conducts multiple fixed-effects models using a time-series data set that will determine the relationship between sea surface temperature and fishery production across 46 countries in the world. Interaction terms are included in the fixed effect models to distinguish between countries that are developing and developed, to see whether they are affected differently. The same model is run with a binary variable indicating whether a country is a Small Island Developing State (SIDS) to see whether they are differently affected than non-SIDS. The research finds a statistically significant decrease in total fishery production with a one percent and a one degree increase in sea surface temperature across all the countries in the sample, as the models were run under log-level and log-log relationships. The research also finds a statistically significant larger increase in total fishery production for developing countries and SIDS, while a larger decrease in fishery production for developed countries. The research goes into economic theories and behaviors that would explain the results from running the models.

Introduction

Global climate change has become the collective action problem of our era and it is affecting our world in many different ways. There are scientists that dedicate their lives to researching the impact of it, and then there are authorities that believe it is a hoax. Climate change is not just melting our poles, the topic is polarizing the people and our societies. An effect of climate change that has become a scientific fact is that our oceans are warming up, and the impact has become apparent in the components of our oceans. The increase in ocean temperatures is causing vital changes to the components of our oceans which will very likely cause major habitat changes. This will further influence the ecology of marine species and important biological processes that can further affect the fish dynamics of our oceans [Porreca, 2020]. Climate change is affecting our world through many different channels and this paper will research the effect of increasing ocean temperatures on fisheries around the world. Specifically, it will investigate the effect of increasing sea surface temperature on total fishery production and it will also analyze whether this effect is different for a country that is a developing versus developed. The research is extended to analyze small island developing states as well, to investigate their relationship with increasing sea surface temperature on fishery production and whether they are affected differently than non small island developing states.

It is more common for developing countries to be dependent on their fishery production for economic growth and nutritional purposes since they do not have other developed sectors that are more reliable and sustainable. Agricultural sectors are more sensitive to climate changes, and these sectors are vital to the future economic growth and nutritional need for developing countries. Among them, small island developing states (SIDS) are the most vulnerable [Blasiak et al., 2017]. According to the United Nations, SIDS account for 1% of greenhouse gas emissions but they are also the most vulnerable to the adverse effects of climate change. There are also developed countries registered as dependent on fishery production, for example, according to the Food and Agriculture Organization such countries include Norway, New Zealand and Croatia. As ocean temperatures are increasing, it is important to investigate whether this trend that has been slowly increasing over the last decades has any effect on the fishery production of countries, but more importantly for those that are dependent on this sector for long-term economic growth. During the COVID pandemic, the United Nations launched its "Building Back Better" initiative as it became apparent that many countries, especially developing states, were suffering heavily from not having resources to fight the pandemic, because their resources are not sustainable enough or have depleted. Research on the effect of changes in fishery production because of climate change is important for the future of the management and maintenance of fishery industries to protect and sustain the sources of economic growth, especially for countries that are dependent on this. It is also essential to maintain these industries and protect them from outside shocks since they play a significant role in the dietary necessity fish has for many of the developing states.

The Gordon-Schaefer model is a bio-economic model that originated in the works of Schaefer in 1954 and 1957. The model looks at fishery catch as a function of the interaction between fishing effort, a species' growth rate, and the carrying capacity of the species' environments [Schaefer, 1991]. The model incorporated historic fishing data to establish maximum economic and sustainable yield, and one can implement sea surface temperature to the model to establish at what sea surface temperature these yields are established. This model shows that sea surface temperature can affect countries differently based on the effort put into fishing, the cost and revenues of fishing, economic shocks as well as environmental shocks. This research wants to analyze whether environmental shocks, such as increasing ocean temperatures, can have an effect on the effort invested in to harvesting fish, or fish production. This effort of harvesting fish is known to be affected by economic factors such as changing prices, costs, revenues and technological progress etc. This research paper assumes that a developing country does not have the same amount of resources as a developed country has to invest in the effort of harvesting fish. Thus, if there is a change in fish dynamics it might be easier for a developed country to recognize this and adapt to it, than a developing country. Therefore, this paper wants to investigate this assumption and how they potentially are affected differently since developing countries do not have the same resources to create industries that are as resilient and adaptable to outside shocks.

In this research paper, a regression model will be constructed to estimate the effect of the independent variable, sea surface temperature, on the dependent variable, total fishery production, for 46 countries between the year 1985 and 2016. An interaction term will be included to the model with a binary variable that will indicate whether a country is developing or developed. In this way, the paper will be able to analyze whether this effect will be different for a country that is developed versus a country that is developing. Another binary variable is created too, which will indicate whether the country is a Small Island Developing State (SIDS) as they are known to be the most vulnerable and sensitive to environmental changes. Doing this will make it possible to see if the fishery production of SIDS is differently affected by the increasing sea surface temperature than non-SIDS. Fixed effects are also included in the model to keep changes across the years and countries fixed, to eliminate omitted variable bias across time and country. A control variable for GDP per capita is also added to control for changes in economic growth across the years and countries analyzed.

Earlier research on the effect of sea surface temperature on fishery production has been established by Zachary Porreca who analyzed the effect of rising temperatures on tuna dynamics in the Pacific. He reveals that there is not much work done on the topic in past literature but in his research he incorporates sea surface temperature to the Gordon-Schaefer model to establish the optimal temperature and effort needed for sustainable fishing, using historic fishing and sea surface temperature data. The paper focuses on establishing where to allocate resources as effort will alter with changes to our environment and he emphasizes the importance of incorporating sustainability into fishery management. Unlike Porreca, I will not be using the Schaefer model but it is a good paper illustrating the relationship between sea surface temperature, effort and catch. This research will contribute multiple regression models to analyze the relationship between sea surface temperature and fishery production to the literature, as this has not been done previously.

Literature Review

Studies have been done estimating the effect of climate change on fisheries by incorporating complex models under certain climate change emissions scenarios to estimate future events. Lehodey et al. does this by using the Spatial Ecosystem And Population Dynamics Model (SEAPODYM) to incorporate the United Nations International Panel for Climate Change A2 scenario on the spatial dynamics of Pacific Skipjack tuna. The A2 scenario is an emissions scenario established by the IPCC that corresponds well to the world we live in today where states operate independently, population is increasing and there are high emissions. He analyzed the effect of oceanic temperature changes on the spatial distribution of the Skipjack tuna catch. Although finding interesting results of decreases in tuna catch in the future under such a familiar scenario, it focuses more on spatial distribution rather than the relationship between sea surface temperature and catch, which this research paper does [Lehodey et al., 2013].

In the study by Sanz et al, Cobb-Douglas production functions were utilized to evaluate the relationship between environmental change and the French Guinea fishery dynamics. Using the production function, they conclude that the sea surface temperature in French Guinea is over the optimal temperature that yields the most catch and they find that sea surface temperature is a very influential factor. Shrimp are not a very migratory species and this study has a sample with a larger variation of species as the total fishery production variable incorporates all fish production, where the majority of species are migratory [Sanz et al., 2017]. Similarly to this study, Garza-Gil et al. uses Cobb-Douglas production functions to investigate the effect of climate change on the Sardine population in the Iberian peninsula. They find that with an increasing sea surface temperature, both the Sardine catch and profits will decline in the future [Garza-Gil et al., 2011].

The Schaefer model is a popular model to use for analyzing the relationship between a climate change factor and fishery yield. The first examination of the relationship between sea surface temperature and fishery yield was done by Fredrick W. Bell who utilized the Gordon Schaefer model to estimate the effect of technological externalities on the production of Northern lobsters. His work has provided the foundational basis for future literature on the relationship [Bell, 1972]. Such future literature include for example Sun et al. who estimated the negative effect of El Niño on mackerel catch in Taiwan, which is an event that annually increases ocean temperatures and is know to cause major disturbance in fish dynamics. This research is interesting as it finds that biomass decreased by 13.2 percent because of increasing temperatures caused by El Niño, but this study focused on the specific effect of the event on biomass, rather than the general relationship between sea surface temperature and fishery production [Sun et al., 2006]. Carson et al. is able to utilize the Gordon-Schaefer model to investigate how cycles in sea surface temperature affect fish growth. They are able to do this by incorporating cyclical growth rates instead of constant growth rates. By doing this replacement, they create a model similar to the reality of cyclical changes to sea surface temperature is able to incorporate the unpredictability of the environment. This research focuses on economic policy and finds a lag of policy-making to cyclical changes in temperature [Carson et al., 2009].

Very current research has been done using the Schaefer model to specifically incorporate sea surface temperature in the evaluation of the effect of increasing ocean temperatures. In Porreca's research, stock biomass has been used as a function of sea surface temperature and by using a feasible least squares regression, he is able to analyze the relationship between fishery effort and temperature [Porreca, 2020]. Similarly, Mediodia et al. used a static fishery model to examine the relationship between tuna catch and sea surface temperature, finding that this relationship is quadratic. Unlike Porreca, the research done by Mediodia did not follow the Gordon-Schaefer model [Mediodia et al., 2020]. In the research at hand, the relationship will not be evaluated by a production functions such as Gordon-Schaefer or Cobb-Douglas, but rather using classic regression models and interaction models.

The effects and implications of increasing sea surface temperature has been studied extensively in the hope of helping fishery management be able to adapt and sustain the fishing industries for the future. Johan D. Bell emphasizes the vulnerability and sensitivity small island developing states have to changes to warmer temperatures and mentions the significant importance tuna catch revenue has for government revenue and GDP. He also stresses the dietary importance of catch and in an earlier research paper professor Bell mentions the Solomon Islands as a country with 92% of its inhabitants dependent on fish for nutrition. He emphasizes the importance fish has for food security for many island states, especially in the Pacific [Bell et al., 2018]. The vulnerability and sensitivity of countries to changes in fishery production has been extensively studied by the Food and Agriculture Organization, a specialized agency within the United Nations that has a goal of providing food security for all nations. Their research finds that African and Southeast Asian fishery industries are most vulnerable to natural disasters and they make considerable recommendations for strengthening the management of these industries [Badjeck et al., 2013].

There is little past literature that conducts a regression model to investigate the relationship between sea surface temperature and fishery production, like the research at hand will. Rather, past literature has focused on conducting various production functions, like Cobb-Douglas or Gordon-Schaefer where yield is a function of sea surface temperature. Though, all research indicates that the increasing ocean temperatures will have detrimental effects on the future of our marine species and aquaculture and there is much research discussing the implications this will have for the future of the management of fisheries and what the policy implications will be. Mora et al. surveys fisheries to evaluate the management and sustainability of fisheries around the world. They come to the conclusion that: "the conversion of scientific advice into policy, through a participatory and transparent process, is at the core of achieving fisheries sustainability, regardless of other attributes of the fisheries", which stresses the importance of sustainable policy-making in the fishing industry [Mora et al., 2009].

Data

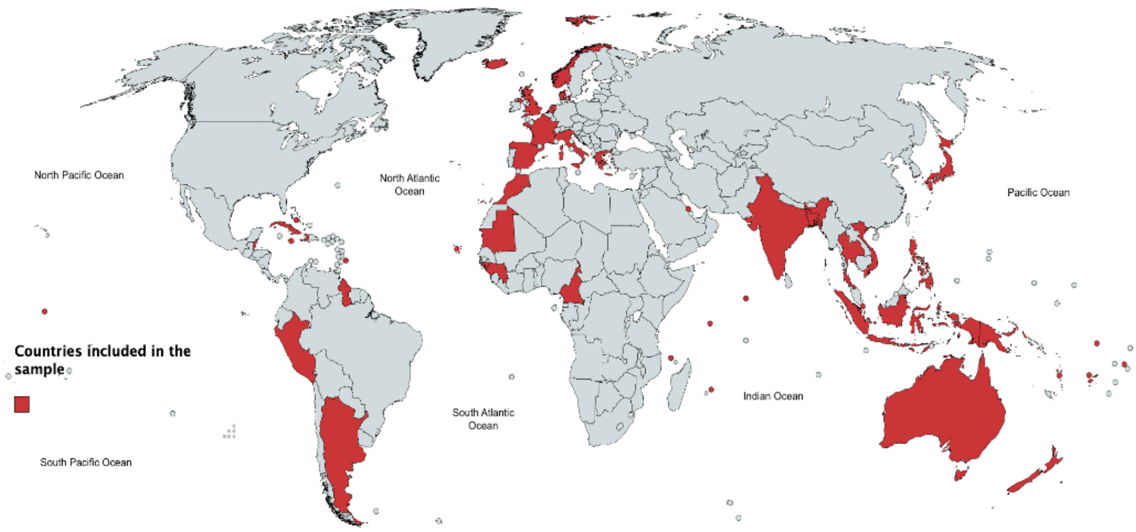

Figure 1: Map of countries in the sample.

The sample includes 46 countries, where 12 of the countries are developed countries, 12 are developing and 22 are recorded are small island developing states. The countries have been randomly selected and small island developing states are also recorded as developing states in the data sample. In figure 1 a map has been created where the countries in the sample have been colored in red to show the variation in the sample.

The National Oceanic and Atmospheric Administration (NOAA) was referred to for data for the independent variable, sea surface temperature, which has been collected monthly between the year of 1985 and present day. OceanWatch Operations Manager Melanie Abecassis created a satellite oceanographic data set that establishes sea surface temperature across the entire world. With her help, a data set generator was accessed where sea surface temperature was established for any time or place using coordinates to create grids where average sea surface temperatures were established within the grid selected. Sea surface temperature is collected in Celsius degrees and the grids were selected from the Exclusive Economic Zones (EEZ) for each of the countries in the sample. Since the data is recorded monthly, yearly averages had to be created for every year between 1985 and 2016.

Developed	Developing	Small Island Developing States
Australia	Argentina	Barbados
Denmark	Bangladesh	Comoros
France	Cameroon	Fiji
Greece	Guinea	Samoa
Iceland	Indonesia	Solomon Islands
Italy	Mauritania	Vanuatu
Japan	Morocco	Bahrain
New Zealand	Philippines	Singapore
Norway	Thailand	Maldives
Spain	Vietnam	Haiti
Netherlands	Peru	Belize
United Kingdom	India	Jamaica
		Tuvalu
		Seychelles
		Cuba
		Papua New Guinea
		Mauritius
		Guinea-Bissau
		Bahamas
		Cabo Verde
		Guyana
		Kiribati

Table 1: The countries that are included in the data sample and in this research paper.

For the dependent variable, total fishery production, data was collected from the World Bank and the unit of production has been measured in metric tons. The data will include measures of the volume of aquatic species caught by a country for commercial, industrial, recreational and subsistence purposes. It will also include harvest from marine-culture, aquaculture and other kinds of fish farming. The data will be collected from 1985 to 2016. This time period has been restricted to this period because the sea surface temperature only exists from 1985 and the World Bank data on total fishery production restricts the data to 2016. The dependent variable will be computed in logarithmic form because there is large variation in production across countries and running it in log will make estimate more accurate.

Later in the research paper at hand, interaction terms are introduced with a binary variable indicating developed versus developing. This will be modelled to analyze whether developing countries are differently affected by the changes in sea surface temperature than developed countries, and vice versa. Additionally, a binary variable indicating whether a country is a small island developing states will be introduced as well, because they are known to be the most vulnerable and sensitive to climate changes, so it is interesting to investigate whether they are differently affected as well. For my control variables, I have collected GDP per capita data from the World Bank, matching the time period of 1985 to 2016.

Descriptive Data Analysis

The mean sea surface temperature in 1985 was 23.5 degrees Celsius while in 2016 it was 24.5 degrees. This shows a mean increase of 1.0 degree Celsius in the 31 years between 1985 and 2016. The mean total fishery production across the 46 countries in the sample was 899,689 metric tons in 1985, which has increased to a 1,578,123 metric tons in 2016. Thus, across the 31 years analyzed ocean temperatures have increased by one degree and fishery production has almost doubled.

The mean sea surface temperature for developing countries is 26.8 degrees Celsius and the mean total fishery production is 924,415.3 metric tons. For developed countries, the mean temperature is lower, being 16.8 degrees Celsius and the mean of total fishery production is higher being 2,024,228 metric tons. Thus, developing countries are surrounded by warmer waters and experience lower production than developed countries that are surrounded by colder waters, but experience higher production.

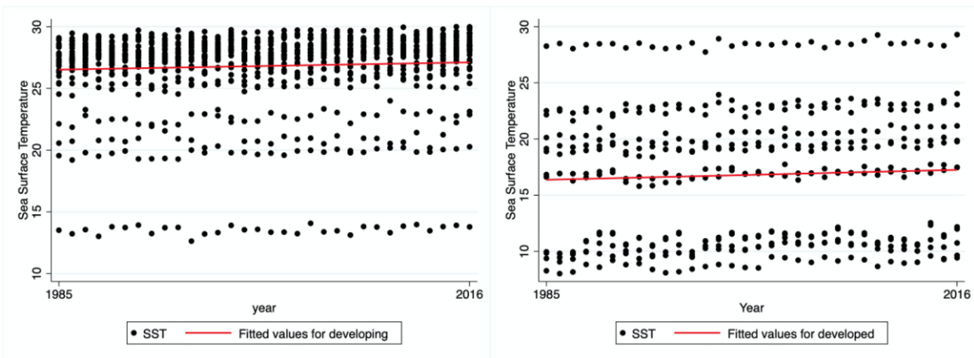

Figure 2: Scatterplots of sea surface temperature across the analyzed timeline. The left scatterplot represents developing countries and the right is for developed countries.

To get a visual representation of the increasing trend of sea surface temperature, scatter plots has been created where sea surface temperature has been scattered across the analyzed timeline of 1995 to 2016. The fitted line that has been plotted as a red linear line confirms the trend of increasing sea surface temperature since 1985. The slope is positive, but seems small as the line is more flat than steep but this is expected as the change in sea surface temperature is expected to be small where an incremental change in sea surface temperature can create larger domino effects on marine and aquaculture, and further fish dynamics and potentially fish production. The same scatter plot was created for developed countries.

The trend seems to be similar for developed countries, as sea surface temperature is increasing across the analyzed timeline. It does not seem like there is much difference in the amount of increase in SST across the timeline between developed and developing, as the slope for the fitted line for both scatter plots seem very equal.

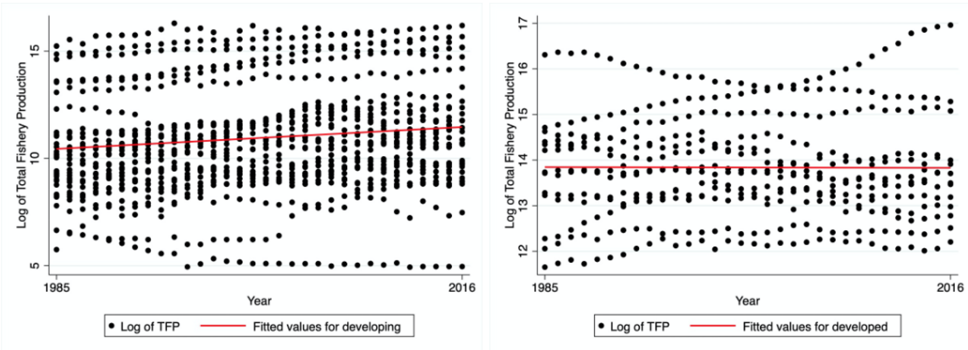

Figure 3: Scatterplots of total fishery production for developing countries (right) and developed countries (left)

To investigate further trends, scatter plots of total fishery production was also created, distinguishing between developing and developed again. Total fishery production was scattered in logarithmic form as there is a large variation within the variable. It seems like total fishery production is increasing across the timeline for developing countries. The world has become more efficient in fishing which can be seen by the positive slope of the fitted line. The scatter plot was then created for developed countries, to see whether there is a different trend for them.

The slope of fishery production for developed countries is pretty flat and shows no increase in fishery production across the timeline. This reflects the difference between developing and developed countries, where developed countries potentially do not have as much of a need for fish as developing. The scatter plots show the difference in dependence for agricultural goods between the two, where developing see an increase in fihsery production.

Methodology

Specification 1:

$$\boldsymbol{logTFP_{it} = \beta_0 + \beta_1 SST_{it} + \epsilon_{it}} \tag{1}$$

where $logTFP_{it}$ is log of total fishery production for country i and year t, and SST_{it} is sea surface temperature for country i and year t. This model establishes the relationship between sea surface temperature and total fishery production without controlling for changes over time, across countries or changes in economic growth. The effect of sea surface temperature on total fishery production is established by β_1.

Specification 2:

$$\boldsymbol{logTFP_{it} = \alpha + \beta SST_{it} + A_i + L_t + \theta logGDP_{it} + \epsilon_{it}} \tag{2}$$

where $logTFP_{it}$ is log of total fishery production and SST_{it} is sea surface temperature for country i and year t. Fixed effects have been included where A_i is the country-fixed effect and L_t is the time-fixed effect. A control variable has been included to account for changes in GDP per capita across time and countries, as the economic growth varies across the countries in the sample. The effect of the control variable is measured by the coefficient θ. This model establishes the relationship between sea surface temperature and total fishery production, but accounts for changes over time and differences across countries. This eliminates omitted variable bias, because by including fixed effects the model is controlling for technological progress by including time-fixed effects and differences across countries by including country-fixed effects. Fixed-effects will eliminate outside noise and will allow for a more accurate estimate of SST on fishery production. There is large variation in the countries in the sample, where for example some are very small and some large so country-fixed effects are essential to include to control for that. Technological progress, which has greatly improved over the last 31 years, is also important for the model to control for, which is done by including time-fixed effects. The variation in economic growth across countries and over time is controlled for by $logGDP$.

Specification 3:

$$\boldsymbol{logTFP_{it} = \alpha + \beta SST_{it} + \gamma(SST_{it} * D_i) + A_i + L_t + \theta logGDP_{it} + \epsilon_{it}} \quad (3)$$

where $logTFP_{it}$ is log of total fishery production and SST_{it} is sea surface temperature for country i and year t. Fixed-effects for country and year is established by A_i and L_t, and $logGDP$ control for variation in economic growth. An interaction term is included to establish whether the effect of sea surface temperature for developing countries is different relative to developed countries, and vice versa. The difference will be established by the coefficient γ and the binary variable, D_i, will be equal to 1 if the country is developing and 0 if developed. Thus, when the country is developing and the binary variable equals to 1, the interacted effect will be established by the summation of β and γ.

Specification 4:

$$\boldsymbol{logTFP_{it} = \alpha + \beta SST_{it} + \gamma(SST_{it} * S_i) + A_i + L_t + \theta logGDP_{it} + \epsilon_{it}} \quad (4)$$

This interaction model is similar to the interaction model in specification 3 but in this model the binary variable, S_i, will equal to 1 if the the country is a small island developing state and 0 if it is not. Similarly, the effect difference when the binary variable is 1 and the country is a SIDS, is established by the summation of β and γ.

To check for robustness, the models will also be run under a log-log relationship, where SST is in logarithmic form. It is more logical to interpret temperature change in degrees, rather than percent, but the models will be run under a log-log relationship to look for potential changes in significance or coefficients. Some countries have been excluded from the sample as they are outliers. China is an example of an outlier in the sample, which experienced the most dramatic increase in fishery production between 1985 and 2016, compared to any other country in the sample. The United States has also been excluded as there is such variation across states and the country itself lies in the middle of two different oceans.

Results

Specification 1 and 2:

VARIABLES	(1) logTFP	(2) logTFP	(3) logTFP	(4) logTFP
SST	-0.127**	-0.128**	-0.0571	-0.0567
	(0.0597)	(0.0605)	(0.0423)	(0.0419)
Year-fixed effect	N/A	Y	Y	Y
Country-fixed effect	N/A	N/A	Y	Y
Control GDP per capita	N/A	N/A	N/A	0.116
				(0.160)
Constant	14.81***	14.39***	12.71***	11.84***
	(1.485)	(1.456)	(0.973)	(1.339)
Observations	1,472	1,472	1,472	1,472
R-squared	0.090	0.100	0.162	0.164
Number of countries	46	46	46	46

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 2: Regression output when running model without any controls, and adding fixed effect and control one by one. N/A means not included and Y means included.

In column 1 (Table 2) the simple model of just estimating sea surface temperature on fishery production was run without any control variables or fixed effects, previously seen under specification 1. From running the model across all countries in the sample, the table states that with a one degree increase in sea surface temperature, all countries in the sample are predicted to see a 12.7 percent decrease in total fishery production. This estimate is established by the log-level model where the coefficient must be multiplied with a hundred percent for the interpretation. The coefficient is also statistically significant at a five percent significance level which shows that the coefficient is statistically not 0. Further, year fixed effects were included in the model to account for changes across time such as the increase in technological progress from 1985 to 2016. During this time, the entire world saw increases in technology and time-fixed effects will be able to control for this. When running the model with time fixed effects in column 2, a one degree increase in sea surface temperature, will decrease total fishery production by 12.8 percent and the coefficient is still statistically significant at five percent significance level. Country-fixed effects are included in column 3, to account for differences across the countries in the data sample. Some are large developed countries and some are tiny island states. When controlling for differences across countries, as well as time, it is evident in column 3 that with a one degree increase in sea surface temperature, total fishery production is predicted to decrease by 5.71 percent. After including country-fixed effects, the significance is no longer there. In column 4, the model is run with time-fixed and country-fixed effects, as well as a control variable for GDP per capita. This was included to control for changes in economic growth across the countries in the sample. The table indicates that with a one degree increase in sea surface temperature, total fishery production will decrease by 5.67 percent. This estimate is still not statistically significant, but indicates a decrease in total fishery production with increases in sea surface temperature while accounting for important changes. The models run are from specification 2, where controls were added to the simple regression model.

Log-level model (Specification 3 and 4):

VARIABLES	(1) logTFP	(2) logTFP	(3) logTFP	(4) logTFP	(5) logTFP
SST	-0.0567	-0.325***	0.112*	-0.185**	0.143
	(0.0419)	(0.0967)	(0.0647)	(0.0808)	(0.104)
(SST x Developing)		0.436***			
		(0.133)			
(SST x Developed)			-0.436***		
			(0.133)		
(SST x SIDS)				0.328**	
				(0.162)	
(SST x non-SIDS)					-0.328**
					(0.162)
Constant	11.84***	9.958***	9.958***	10.66***	10.66***
	(1.339)	(1.617)	(1.617)	(1.495)	(1.495)
Observations	1,472	1,472	1,472	1,472	1,472
R-squared	0.164	0.187	0.187	0.177	0.177
Number of country_id	46	46	46	46	46

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3: All regression models are run under a log-level relationship.

Following are outputs of running the interaction models in specification 3 and 4, under a log-level relationship (Table 3). All the models have included country and time-fixed effects, as well as a control variable for GDP per capita. In column 1, the model was run across all countries in the sample to determine the overall effect of increasing sea surface temperature on fishery production. The coefficient is the same as the coefficient in column 4 (Table 2) where the same model was run. It indicates that with a one degree increase in sea surface temperature, total fishery production is predicted to decrease by 5.67 percent. This shows a negative relationship, but the coefficient is not statistically significant and not statistically different than 0.

In column 2, the model was run with the interaction term for developing countries, to establish how developing countries are differently affected by increasing sea surface temperature, relative to developed countries. Thus, developed country is the baseline in this model and what the result will be compared to. The coefficient on SST is β and the coefficient on interaction term (SST x Developing) is γ so the interacted effect is computed by the summation of these. Thus, with a one degree increase in sea surface temperature, developing countries are predicted to see a 11.1 percent larger increase in fishery production than the baseline which in this model is developed countries. The coefficient γ is statistically significant at a one percent significance level and indicates that there is statistical difference between developing and developed countries in their production's response to changing sea surface temperature. The coefficient on SST in column 2 is statistically significant as well and indicates that the effect of sea surface temperature on fishery production for developed countries is negative and statistically different than 0.

In column 3, the model was flipped and run for developed countries. The coefficient, γ, on the interaction term (SST x Developed) is the negation of the coefficient on the interaction term (SST x Developing) in column 2. Thus, with a one degree increase in sea surface temperature, developed countries are predicted to see an astonishing 32.4 percent larger decrease in total fishery production than developed countries. The coefficient on the interaction term is statistically significant and indicates that there is statistical difference between developed and developing countries. The coefficient on SST in column 3 shows the relationship between sea surface temperature and total fishery production for developing countries, and the coefficient is positive and statistically significant at a ten percent significance level.

In column 4, the model was run with a different binary variable that indicates whether a country is a SIDS. Similarly, by adding the coefficients it is apparent that with a one degree increase in sea surface temperature, SIDS are predicted to see a 14.3 percent larger increase in total fishery production than non-SIDS. The coefficient on the interaction term is statistically significant at a one percent significance level and again shows that the difference between SIDS and non-SIDS is statistically different. The coefficient on SST in column 4 shows the relationship between sea surface temperature and fishery production for non-SIDS. The coefficient is negative but not statistically significant and shows that for non-SIDS there is a negative relationship between sea surface temperature and fishery production.

The last column flips the previous model around and runs the interaction model for non-SIDS. The table shows that with a one degree increase in sea surface temperature, non-SIDS are predicted to see a 18.5 percent larger decrease in fishery production than SIDS. The coefficient on SST in the last column indicates the relationship between sea surface temperature and the fishery production for SIDS which is negative and statistically significant at a one percent significance level.

Log-log Model (Specification 3 and 4):

VARIABLES	(1) logTFP	(2) logTFP	(3) logTFP	(4) logTFP	(5) logTFP
Log SST	-2.284***	-3.808***	2.388	-3.082***	3.693
	(0.780)	(1.128)	(1.566)	(1.008)	(2.853)
(Log SST x Developing)		6.196***			
		(2.172)			
(Log SST x Developed)			-6.196***		
			(2.172)		
(Log SST x SIDS)				6.774*	
				(3.424)	
(Log SST x non-SIDS)					-6.774*
					(3.424)
Constant	17.59***	7.830**	7.830**	9.409**	9.409**
	(2.555)	(3.665)	(3.665)	(4.038)	(4.038)
Observations	1,472	1,472	1,472	1,472	1,472
R-squared	0.170	0.183	0.183	0.180	0.180
Number of country_id	46	46	46	46	46

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4: All regression models are run under a log-log relationship.

Further, it was decided that the model should be run under a log-log relationship as well, to investigate whether having SST in logarithmic form will change the magnitude of the coefficients, the significance or maybe the sign of the coefficient. From running the model across all countries in the sample, without any interaction terms, it is evident that with a one percent increase in sea surface temperature, the total fishery production is predicted to decrease by 2.28 percent. Compared to running the model under a log-level relationship, the overall effect is statistically significant at a one percent significance level when the model was run under log-log relationship. That is the only difference between running them under the two relationships, as the significance of the interaction terms are similar as running the model as log-level.

In column 2, the interaction term is included where log of SST is interacted with the binary variable D_i indicating a developing country. The summation of the coefficients tell us that with a one percent increase in sea surface temperature, the total fishery production of developing countries is predicted to see a 2.39 percent larger increase than developed countries. The coefficient on the interaction term is statistically significant at a one percent level and indicates that there is still statistical difference between developing and developed countries. The coefficient on log of SST represents the relationship between sea surface temperature and total fishery production for developed countries and the coefficient is positive and statistically different than 0.

In column 3, the previous model was flipped again to analyze the model from the perspective of a developed country. The interacted effect shows that with a one percent increase in sea surface temperature, developed countries are predicted to experience a 3.81 percent larger decrease in total fishery production than developing countries. γ is statistically significant again and shows that there is statistical difference between developing and developed countries. The coefficient on log of SST is not statistically significant and shows the relationship between sea surface temperature and fishery production for developing countries, which is positive.

Further, the binary variable, D_i, was swapped with S_i again to investigate small island developing states. In column 4 the interacted effect is established and it shows that with a one percent increase in sea surface temperature, SIDS are going to experience a 3.7 percent larger increase in fishery production than non-SIDS. The coefficient on the interaction term is statistically significant and shows that there is statistical difference between SIDS and non-SIDS. The coefficient on log of SST reflects the relationship between sea surface temperature and fishery production for non-SIDS. This relationship is negative and statistically different than 0. The last column runs the model for non-SIDS. It is apparent that with a one percent increase in sea surface temperature, the total fishery production for non-SIDS is predicted to see a 3.1 percent larger decrease than SIDS. The coefficient on log of SST in the last column represents the relationship between sea surface temperature and fishery production for SIDS, and this coefficient indicates a positive relationship between SST and fishery production for SIDS.

Discussion

Interpretation

For the research at hand, it might be more reasonable and logical to interpret the results under a log-level relationship, as it is easier to imagine a one degree change, rather than a one percent change in temperature. Earlier in the descriptive analysis, when describing the sample, it was apparent that between 1985 and 2016, the mean sea surface temperature across the entire sample increased by 1.0 degree Celsius. Therefore, when interpreting the log-level output, the percent change can be interpreted as the entire change in fishery production for a country from 1985 to 2016. So, across the 31 years analyzed, all the countries saw an overall decrease in fishery production of 5.67 percent. If the trend of increasing sea surface temperature continues, the entire sample will continue to see decreasing fishing productions for the future. The effect is seen as negative but is not statistically different than 0, but when run under a log-log relationship the effect becomes statistically significant. This is seen in column 1 (Table 4) where a one percent increase in SST, will lead to a 2.28 percent decrease in fishery production. This makes sense as a one percent change in sea surface temperature is smaller than a one degree change.

In science, a percent change in temperature technically does not exist and for future research the model should consider to use absolute temperature units like Kelvin, instead of Celsius. Celsius and Fahrenheit are based off relative scales, for example they have different freezing and boiling points, so percent changes would not be the same in Celsius and Fahrenheit. This further supports the log-level interpretation, rather than log-log, because sea surface temperature is interpreted as a degree change rather than percent change.

This research wants to analyze whether some countries are more vulnerable to climate change, relative to others and this was done by introducing interaction terms. When running the model under a log-level relationship, there is no effect that confirms the assumption made in this research paper. It seems that SIDS and developing countries will actually see larger increases in fishery production than developed countries and non-SIDS. The model also shows that the difference between developing and developed and SIDS and non-SIDS are statistically different as well. Also, by looking at the coefficients of SST, one can determine whether the effect of sea surface temperature on fishery production for each type of country is statistically different than 0. It is evident that developing countries and SIDS have a positive relationships, while developed and non-SIDS have statistically significant negative relationship between sea surface temperature and fishery production. The story is similar when running the model under a log-log relationship.

Supply and Demand-side effects

There are some potential reasons for why developing countries see larger decreases in fishery production while developed see larger increases, which goes against the earlier assumption made in this research, where developing are more vulnerable to increasing sea surface temperature. From the descriptive analysis it is apparent that developing countries are surrounded by warmer waters while developed are surrounded by colder. This could potentially mean that there are supply-side effects affecting the model and that warmer waters have more fish than cooler waters. It is known that there are more species in general closer to the equator than closer to the poles so this could be making it so that the model indicates that developing countries see larger increases in fishery production than developed countries, just because there is more fish in warmer waters. It could also be so that changes in colder waters is more disturbing for the specific fish populations closer to the poles which makes developed countries in colder waters more affected by incremental changes in sea surface temperature.

There could also be demand-side effects that affect the model making developed countries seem more vulnerable than developing. The demand for fishing activity in developing countries and especially small island developing states must be much larger than for developed countries, because it might be the only profitable sector the developing country is relying on. As discussed earlier under the assumption made in this research, developed countries have other more resilient, developed and sustainable sectors such as manufacturing, service and industry. On the other hand, developing countries are dependent on their agricultural sectors such as fishing for employment, income, exports and nutrition. Thus, there is a larger demand for fishing activity because other options for income, nutrition and economic growth is limited. This is the fundamental difference between developing and developed countries. This could be making it so that it seems like developed countries are more affected, when they just do not need to fish as much anymore as developing countries do. This can be seen in the descriptive analysis, where fishery production is increasing for developing countries, but is very flat for developed countries, indicating less increase in fishery production in the last 31 years. The demand-side effect is also supported by Johan Bell, who stresses the extensive need small island states have for fish for many reasons and that increasing temperatures can lead to food insecurity and economic decline [Bell et al., 2018]. This also explains why SIDS see a much larger increase in fisher production, becuase it might just be reflecting the dire need for SIDS to produce fish.

Fish farming, also known as aquaculture, has become a popular way to breed fish to increase the production of it. Norway, for example, started breeding fish through sustainable fish farming in 1970, while some countries have been doing it for many years. It is a way for countries to be able to supply the large need for fish, but also maintain wild fish populations in the oceans. It is a response to overfishing and the depletion of our most valuable species. Aquaculture has been included in the model as it is included in the dependent variable total fishery production.

Limitations

The act of fishing can contribute to climate change itself as fleets, vessels and fishing boats can be dirty and create spills which can also contribute to disturbances in fishing dynamics. Thus, the model suffers reverse causality as fishing itself can increase sea surface temperature which can have a further effect on fishery production. Though, overall fishing will probably have a minimal effect on sea surface temperature, as there are many other more major variables that can change sea surface temperature more than fishing itself. There is a problem of overfishing though, which means depleting a source for fish which is common for developed countries to do in developing regions. They establish agreements and impose on developing countries' territories and overfish and deplete their resources. This shows how today's overfishing can hurt future fishing.

There might also be some measurement errors that can affect the model. These fishing agreements discussed above are difficult to account for in the model but might support the supply-side effects discussed earlier. If developed countries establish agreements to fish in developing countries' territories, it must mean there is more fish in these regions. But, it can also mean there is measurements errors when measuring fishery production, as developed countries produce fish that do not come from their own territory. It is also common for many countries to lie on how much fish is actually produced. This might also lead to measurement errors. There are environmental scenarios that can be difficult to account for as well such as El Niño which according to Sun et al. decreases biomass in mackerel by 13.2 percent because of the increases in temperatures[Sun et al., 2006]. It is outside this research's scope to be able to incorporate all these measurement errors.

It is difficult to think of any omitted variable bias, as the fixed effects that are included in the model control for most. Sea surface temperature is an exogenous variable, so there could be outside influence affecting sea surface temperature that have not been controlled for. But, when including country-fixed effects and time-fixed effects, the model is able to control for omitted variable bias because changes over time, such as technological progress has been controlled for with time-fixed effects. There is a large variation in the countries in the sample since the research investigates differences between developing and developed countries, which are very different from one another. This is controlled for by country-fixed effects, which controls for differences across countries where the differences are constant over time. The model also controls for economic growth over the timeline by including the control variable for GDP per capita. Fishing effort and the management of fisheries is difficult for the models to account for which could pose for omitted variable bias. Climate changes, such as increases in sea surface temperature could be affecting fishing effort which further affects fishery production. This can be controlled for when using the Gordon-Schaefer model, but not when using this type of a statistical approach.

Conclusion

Although the research found results that did not match the assumption made previously, it does find an overall negative relationship between sea surface temperature and fishery production. This makes it evident that with the increasing trend of sea surface temperature, a large number of countries from very different places in the world are all negatively affected. Climate change does not discriminate against countries, so it does not matter whether a country is developing or developed; the overall trend is negative. From the interaction models it is evident that developed countries are more affected by changes in sea surface temperature, relative to both developing countries and small island developing states. This is not what was assumed, but the relationship can be explained by the forces of supply and demand-side effects. There might be more species of fish in warmer waters (supply-side) and/or there could be a higher demand for fishing activity in developing countries and SIDS because there are no other option for nutrition, employment or income (demand-side). These would explain why developing countries see such a larger increase in fishery production, relative to developed countries.

There is little work done investigating the relationship between sea surface temperature and fishery production in past literature, so that is the contribution this research has to literature. For future research, it could be beneficial to find data that does not include aquaculture, or fish farming. This could eliminate the influence it has on the effect, as fish farming is a result of overfishing and reduced wild life populations in the oceans. Future research would also benefit from being able to account for differences in the demand for fish across the countries, as some countries have a larger need for fish to survive than other countries. This is the most reasonable explanation to why developing countries see larger increases in fishery production relative to developed, because developed countries just do not have the same need for it.

Past literature strongly emphasize the danger of the increasing trend in sea surface temperature for fishery production and the efficiency of fisheries, and the overall effect estimated in this research reflects this negative relationship. Climate change is composed by unpredictable changes in our environment that can not be controlled for, and they affect the livelihoods of everyone in different ways. This is evident from the interaction models and the difference established between developing and developed, SIDS and non-SIDS. There is a lot of research that suggest that with warming ocean temperatures around the equator, there will be massive migration of fish species towards the poles. This could cause irreversible changes that will affect developing countries more than developed countries, especially if demand-side effects play into effect in the model, and developing countries have a higher demand and need for fishing. Thus, it could be beneficial for countries that suffer from environmental shocks to incorporate sustainable fish farming to potentially increase the supply to match the demand needed for fish. This could further create more employment, as well as larger supply of fish for potential exports.

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