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Impacts of El Nino on renewable energy industry and fishery and aquaculture industry around the pacific

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Abstract. The effects of climate change on the world economy come into view in recent years, in El Nino is one of the most intricate and solid problems in predicting its occurrence and mitigating its effects. Former studies include its impacts on fishery and aquaculture, agriculture and major crops and the renewable energy market. Possible impacts include reproductive failure of fish, worsening well-being of people in coastal consortiums, decreasing production in maize, especially in warmer regions and decreasing efficiency and quantity of wind power production. Observed regions varied from the South American Coast and Peruvian waters to Malaysia, but neither of them compared the differences between each region as their major part. In this paper, fixed effects and dummy variable regression are used to evaluate El Nino's impact on fishery and renewable energy industries and contrast the differences between Japan, the USA and Australia. Results show that El Nino has a clear restraint on both industries but a stable increase in renewable energy production makes the relationship positive. Among the countries, Japan is the most restrained in both industries while the USA is the least affected. Among the different renewable energy sources, solar energy is promoted while hydro energy is restrained.

Keywords: El Nino, Aquaculture industry, the Pacific, effect

1. Introduction

El Nino is commonly referred to as a Pacific basin-wide increase in both sea surface temperatures in the central and eastern equatorial Pacific Ocean and sea level atmospheric pressure in the western Pacific (Southern Oscillation) [1,2]. The most serious ones happen on an interval of seven to eleven years but are up to further research. This phenomenon has extended influence over countries around the Pacific, bringing increasing risk of drought, flood, and related disasters and diseases and spreading infectious diseases such as Malaria and Mosquito-borne viral diseases [3]. No matter whether drought or excessive rainfall shocks the countries' economies unexpectedly. In their study [4], Generoso et al found that there was a lower average rate of growth in contemporaneous El Nino phases compared to neutral and La Nina phases. There was also a significant dispersion of real GDP growth rates across countries, suggesting that heterogeneity between countries and many other factors contributed to the differences in GDP growth rates [4].

Reviews published as early as the 1990s, examine El Nino's effect on fishery. One study off the South American coast points out that the El Nino event in 1982-83 was catastrophic due to reproductive failure caused by changes in the food composition of fish and the breakdown of their

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underlying food base. It wasn't visible, though, because of previous overhunting [5]. Other regional assessments of Peruvian waters [6] and the Philippines [7] produce similar results. In 2014, a book [8] summarizes the studies. It provides the development of El Nino, its diversity, our imperfect predictability, an overview of ENSO impacts on ocean conditions, weather patterns and oceanic productivity, regional assessments of its impacts on Major Fishing Areas (FAO), aquaculture and global food supply, and inland fisheries showing that El Nino impacts vary due to ENSO event type and the society's dependency on certain industries [8]. People in small coastal consortiums are especially influenced [9]. The lack of species such as sea urchins and crabs [10] put people on low incomes, bringing them into precarious conditions even without running water and electricity [11]. It is also reported [10] that the effect of El Nino is twice as large in the tropics when compared with that of the temperate areas because agriculture and primary commodity exports, such as valuable commercial fishes, represent a major source of these economies.

Agricultural production is another focus of the impacts of El Nino. In a review that examines its impact on the world's major crops such as soybean and wheat, T. Iizumi, J.-J.Luo, et al establish that 22 to 24 percent yields are reflecting significant negative and 30 to 36 percent reflecting positive impacts of harvested areas worldwide. Geographically, warmer and drier climate conditions during El Nino years have more negative effects on regions such as maize in Zimbabwe, soybean in India and rice in Indonesia while cooler and wetter weather conditions are often correlated with positive impacts [12]. In his study, Shuai et al. [13] found that the maize production in China during El Nino experienced a yield increase in the north and a decrease in the south.

The ENSO impact on renewable energy has just come into view in recent years. ENSO exerts strong influences on climate variables that renewables rely on, such as precipitation, drought, wind energy and solar radiation [14]. In a study, using Wavelet analysis of wind and solar production in Malaysia [15], authors conclude that the decrease in wind-speed in the already low windspeed region significantly influences the output of wind turbines. Rising temperature decreases turbine efficiency, and strong wind strength challenges turbines' design. Still, the temperature rise brings less rainfall, thus less cloudiness, allowing more solar energy production [15].

Therefore, this research aims to use the fixed effect to analyze the effect El Nino has on the traditional industries (fishery) and newly developed industries (renewable energy) and compare country-specific in fluence (Japan, the USA and Australia). El Nino most directly affects fishery, and this sector has been playing an important role in the overall growth of global economies. The renewable energy sector is chosen for "newly developed industries" because this sector has just risen due to technological advancements and may become one of the dominating industries in the future. Since El Nino is a worldwide phenomenon that matters with the development of the world's economy developments, Japan, the USA and Australia are chosen to represent countries to the east, west and south of the Pacific. The results of this study will analyze the heterogenous effects El Nino has on the two industries, specify differences in the effects between the countries and provide possible insights for industries to prepare for climate changes according to the corresponding situation, mitigating the effects of unexpected harm as much as possible. As for individuals, the effect of El Nino, especially in the renewable energy sector, shall be paid more attention to. Renewable energy matters to everyone more in the future because technology is driving people to use cheaper, environmentally friendly energy.

2. Method

2.1. Datasets
To form connections between El Nino occurrence and corresponding fluctuation in fishery and renewable energy production in Japan, the United States and Australia, this study uses three sea surface temperatures (SST) and two economy datasets. SST changes are assumed to represent El Nino events because they usually bring sharp rises in SST. Through observation of SST changes, this study can identify major El Nino occurrences and thereby analyze their influence.

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The SST dataset for Japan [16] was most recently updated in 2023 by the Japan Meteorological Agency. It contains seasonal and annual anomalies of sea surface temperature of Sea off Kushiro (Numbered E1) between 1900 and 2022. The sudden fluctuations of SST may imply the impacts of El Nino and La Nina.

The SST dataset for the USA [17] comes from daily observation data from the Shore Station Program, Santa Barbara (34.403860, -119.692774). It provides daily sea surface temperature data of the west end of Santa Barbara harbor from January 1, 1955, to June 30, 2023. To simplify the dataset, the annual mean SST is calculated from 1955 to 2023 instead of daily observations. Years with too many missing values and incomplete months (like 2023) are marked or ignored according to their conditions.

The SST dataset for Australia [18] contains the annual anomaly and the ten-year rolling average of sea surface temperature of the Coral Sea from 1900 to 2019. The Coral Sea is the tropical sea in the southwestern Pacific and is off the northeastern coast of Australia. The annual anomaly is calculated from the United States Department of Commerce National Oceanic and Atmospheric Administration (NOAA) Extended Reconstructed Sea Surface Temperature Version 5 (ERSST v5) dataset.

The Renewable Energy dataset is a comprehensive collection of global renewable energy data from 1965 to 2022. The dataset contains the consumption and production of hydropower, wind, solar, biofuel, and geothermal energy production from around the globe. [19] Data for modern renewable energy production for Japan, the USA, and Australia are selected.

The dataset for the marine economy, most recently updated in May 2023, comes from The OECD Sustainable Ocean Economy Database [20], which synthesizes ocean-related datasets from the Environment Directorate, the Trade and Agricultural Directorate and others to reach better availability and comparability. The datasets contain different aspects of the marine economy in different countries, in which “Total aquaculture production, marine and partly-marine species in thousand tonnes” is selected for Japan, the USA and Australia.

2.2. Fixed Effect Regression Model

The datasets are collected and combined into panel data from 1965 to 2022 with columns of countries, years, SST, renewable energy production and aqua production. To calculate the effect El Nino has on the industries and considering the great distinctions of climates and economy between countries, individual fixed effects are used for both industries. Countries are given indices. The basic formula of the fixed effects regression model is as below:

$$Y_{it} = \beta_1 Xit + \alpha_i \tag{1}$$

Where Y_{it} represents renewable energy and fishery production; Xit represents the SST anomalies of each country; a represents unknown intercepts for each country that varies between countries but not significantly over time, such as the significance of certain industries in the economy; β_1 is what we want to estimate, which is the effect of SST on the industries given the characteristics of countries.

Next, time effects are combined into individual effects because some factors vary through time but do not vary apparently between countries such as natural economic growth. So the formula becomes:

$$Y_{it} = \beta_1 Xit + \alpha_i + \lambda_t \tag{2}$$

Where λ_t represents the time-fixed effects, other things equal.

Dummy variable regression is also introduced to estimate the impacts. Countries will be handled as the dummy variables, where Japan is 1, the USA is 2 and Australia is 3. The formula is:

$$Y_{it} = \beta_0 + \beta_1 X1 + \beta_2 X2 + \beta_3 X3 \tag{3}$$

Where X1 is the countries, X2 is the years, X3 is the SST, other things equal.

3. Results

To better visualize and compare the trends of SST, aqua production and renewable energy production in the three countries, Figure 1 is drawn.

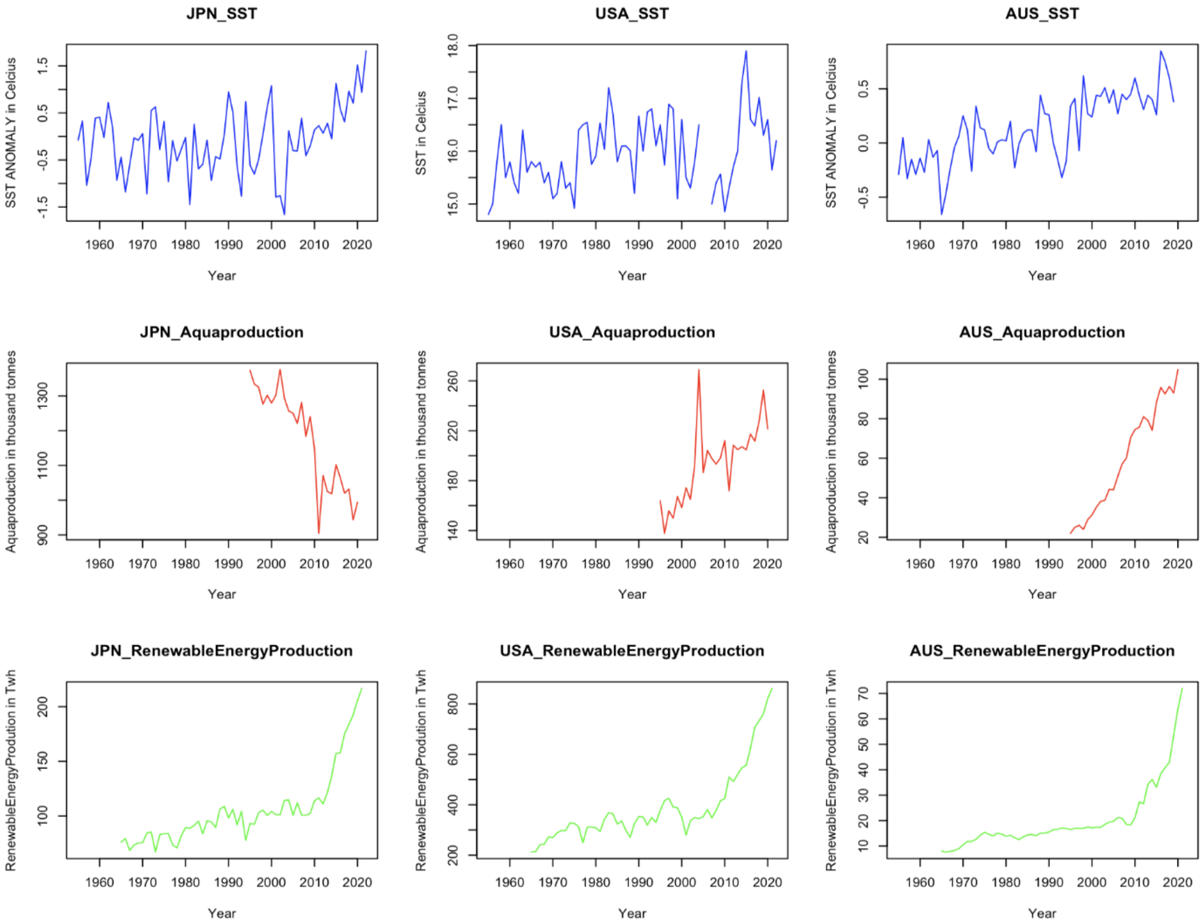

Figure 1. Comparison between countries and Industries.

SST fluctuates in all three countries in cycles of about five years, but there is an overall warming trend of ocean water probably due to global warming. A sudden increase is usually followed by deep downfalls, some of which correspond to the El Nino and La Nina events, where SST usually rises and falls. For example, during the El Nino event around 1982 to 1983, there were sharp increases in SST for all countries. In the 2016 El Nino event, there are sharp increases for the USA and Japan but not Australia. Trends in aqua production vary greatly within each country. While the USA and Australia keep increasing trends, Japan has falling aqua production. Even though Japan has a falling trend, it still has production of about 900 thousand tonnes, greater than the other two countries. While Japan and the USA had sudden fluctuations during the 2010- 2011El Nino event, Australia seems to have milder fluctuations. It may indicate that Australia is less affected by the El Nino events because of its distance from the major part of the Pacific.

All three countries follow similar trends in renewable energy production, with a slow growth rate before 2010 and quick advancements after 2010 as technology develops. However, there is no apparent fluctuation in renewable energy production with SST changes.

The results of the individual, time-fixed effect and dummy variable regression are shown in Table 1.

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Table 1. Fixed Effect Result

β	Renewable Energy	Fishery Production
Individual Fixed Effect	41.98 (11.16)	-48.32 (14.88)
Individual and Time fixed effect	-12.38 (11.84)	-53.11 (23.48)
Dummy Variable regression	20.62 (0.87)	-26.86 (1.31)

Overall, fishery production is more restrained by El Nino. The three β fishery productions all show a relatively apparent negative relationship between SST changes and fishery production. It corresponds to reality because it is known that El Nino poses a direct impact on ocean water and, reasonably, the fishery industry is closely related to it. Since the combined fixed effect has a coefficient only slightly lower than the individual fixed effect, and the coefficient for “year” in the dummy variable regression is only 0.86, it can be inferred that time has less effect on production.

The β for renewable energy production seems to be hesitant between positive and negative relationships, signifying the possibility of promotion and restraint or no relationship at all. When time isn’t fixed, there is a strong positive relationship. As also shown in Figure 1, production rose faster than SST, especially after 2010, when renewable technology advanced globally and when society calls for an environment-friendly way of living, making β a positive value. When time is fixed, the relationship turns negative because the changes brought by time are eliminated, showing that El Nino has certain negative impacts on renewable energy production and time plays a great role in measuring the relationship.

In the fixed effect cases, the standard error is relatively big while the r-squared is relatively small. This may be caused by the already large scales of dependent variable (for example Japan has about 1000 thousand tonnes in aquaculture production), the sharp fluctuation of climate variables and other factors contributing to the impacts, making it hard to fit a more perfect line. Further analysis of the El Nino impact on this industry will be discussed in the next section.

4. Conclusion

In this section, the objective is to summarize the main results, elaborate on the different impacts between countries and industries, provide possible reasons behind the differences and discuss the limitations of datasets and the methods.

Overall, fixed effect and dummy variable regression show that El Nino has a clear restraint on the fishery industry. Time plays a minor role in the overall impact, but countries differ a lot from each other because the dummy variable regression shows extremely negative numbers for β for the countries. Time does play an important role in measuring El Nino’s effect on renewable energy production. The rapid advancement in technology brings a surprising increase in production, forming a positive relationship between SST changes. However, when time is also fixed, the relationship turns negative, meaning there exist certain restraints.

To further examine the different effects between countries, dummy variable regression for every country is done. Results for fishery show that Japan is the most mitigated with the β of -111, while the USA and Australia are impacted much less. The fishing ground near Hokkaido is one of the greatest fishing grounds in the world, supporting most of the fishing industry in Japan. The dataset for SST anomalies is also selected from the sea of Kushiro, East of Hokkaido. Sharp fluctuation in this region impacts severely the production of the whole country. So the extreme β here is reasonable. The USA has fishing grounds all around the coast, in Alaska, and in the western Pacific. When fish like salmon, squids and rockfish move to the cooler North in El Nino events [21], fishery production, possibly, wouldn’t be much mitigated due to its large geographic scale. Australia is at a greater distance from the Pacific, with marine heatwaves striking its other coasts, influencing fishery production [22], so the result may not show much impact, particularly from El Nino events.

Results for renewable energy production show positive relationships for all countries, with β 23 for Japan, 34 for the USA, and 18 for Australia. The USA has the most positive relationship, which may be attributed to its vast area and variety of stable resources that keep production rising fast each year. For example, the USA has a great hydroelectric power station in the Columbia River Basin and some smaller ones in 34 of the states while the other countries do not have similarly well-known hydroelectric power stations. Among all renewable energy, solar energy is the most promoted because clear skies caused by less rainfall allow more solar radiation and also because of increasing area, efficiency, and stability of solar panels. Hydro-energy is less promoted because El Nino causes droughts in some regions and floods in other regions. The effect then becomes dependent on the locations of water resources.

However, the results are inaccurate and aren't very specific. Limitation exists in both the datasets and the method. In the dataset, only SSTs from East of Hokkaido, Santa Barbara station, and Coral are recorded. Meanwhile, the datasets of the industries record the overall production from all over the countries. The mitigating effect of one region may be canceled out by the promoting effect of another region. For larger countries like Australia and the USA, this limitation is much more apparent than in smaller countries like Japan because regions vary much with each other in large countries. For instance, the mitigation effect on fishery production in Japan is very apparent, as shown by the β of -111. The β for the USA and Australia has less apparent values, partly because of this limitation. Therefore, the result produced by the data may not show a significant and accurate influence on the industries in specific places but will provide an overall trend of impacts. The limitation of the method is that it can only show the relationship between SST and production rather than the direct influence of El Nino events, though SST change is a major phenomenon and representation of El Nino events. In addition, the distinct effects that different types (Extreme El Nino, Moderate Eastern Pacific El Nino, Moderate Central Pacific El Nino, and Coastal El Nino) [8] of El Nino have on the industries cannot be specified using this method because all types are coerced into the SST-anomaly variable to do the fixed effect. (For example, moderate El Nino is said to have positive effects on industries, but extreme El Nino has devastating effects.)

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