Accounting for price responses in economic evaluation of climate impacts for a fishery

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Abstract

The present study evaluates the economic impacts of fluctuations in anchovy (*Engraulis spp*.) catch in Gyeong-Nam (GN) province, South Korea, arising due to warming seawater, accounting for the effects of the responses of the anchovy price. It combines an inter-regional input-output (IRIO) model of two regions (i.e., GN province and all other provinces combined) with a simultaneous equation system (SES) of anchovy supply and demand functions estimated to make projections of the price and quantity of anchovies based on two greenhouse gas (GHG) concentration scenarios (i.e., representative concentration pathway (RCP) 4.5 and 8.5). Results indicate that estimates of the economic impacts for the two regions will be biased if we consider only the quantity (harvest) change when computing the economic impacts without also accounting for the effects of the price responses. None of the previous IO-based economic impact analyses of fisheries account for the price effects induced by a quantity shock. This study fills this critical void by considering such effects.

Keywords: Climate change, anchovy fishery, South Korea, price response, inter-regional input-output model

1. Introduction

The incessant increase in CO_2 emissions in the past several decades has caused global warming, which is a major aspect of climate change and has brought about rising air and seawater temperatures, glacier shrinkage, and rising sea levels. The fifth assessment report by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2014) reveals that, over the period from 1880 to 2012, the global average temperatures of the combined land and ocean surface rose by 0.85°C [0.65 to 1.06]. Further, it is estimated that by the end of the 21st century (2081–2100), the global mean surface temperature will increase by 2.6°C to 4.8°C (under representative concentration pathway (RCP) 8.5[1]), compared to the period from 1986 through 2005 (IPCC, 2014). Rising seawater temperature, which is one of the many negative impacts of global warming, affects marine ecosystems and fish productivity.

As the seawater temperature rises, some fish species migrate to higher latitudes, while other species move to deeper waters. From 1968 to 2014, the sea surface temperature (SST) in the waters adjacent to the Korean Peninsula rose by 1.19°C (National Institute of Fisheries Science, NIFS; 2016), which is well above the global average increase in SST, thus increasing the harvest of warm-water species (e.g., mackerel and squid) and decreasing that of cold-water species (e.g., pollock and saury) (Kim et al., 2014; Kim et al., 2007).

Anchovy (*Engraulis spp.*) is a warm-water species living in the surface waters off the coast of Southern Korea. The species is vital to maintaining the marine food web in Korean waters because it is a prey species for many other species. Its harvest has grown since the late 1990s. Since 1993, the anchovy catch has been hovering around 200,000 mt. The catch from the fishing grounds in the waters off Gyeong-Nam (GN) and Jeon-Nam (JN) provinces in the

[1] RCP is a greenhouse gas concentration trajectory adopted by the IPCC. Four pathways were used for climate modeling and research by the IPCC fifth assessment report in 2014.

Republic of Korea (ROK) accounts for 80% of the total anchovy harvest from Korean waters. Over 60% of anchovy harvest is made by Anchovy Drag Net vessels (Song, 2018). Owing to warming sea surface waters in the South Sea, the anchovy catch has fluctuated wildly in the area, and the fishing grounds have moved to higher latitudes, thus affecting anchovy fisheries and the dependent economies, especially those of the GN and JN provinces.

Anchovy fishery in ROK is characterized by an open access fishery with license limitation. There is no total allowable catch (TAC) or quota imposed on anchovy fishery in ROK. However, since the anchovy catch has been declining recently due to a low level of its biomass, the government designated the fish as the species whose stock needs to be recovered, and has made annual assessment of the stock for efficient management. It is possible that the government will implement a TAC policy for the species in near future.

The present study evaluates the regional economic impacts of violent fluctuations in anchovy catch in the GN province in South Korea, caused by rising SST, for four different years (2020, 2030, 2050, and 2100). GN is chosen as the study region because the largest amount of raw anchovy is landed at the province's ports. In 2013, 122,067 mt of raw anchovy was landed in the province, generating a total ex-vessel revenue of 173.1 billion Won.[2] The landed raw fish accounts for 54% of the total anchovy catch from Korean waters (KOSIS, 2020a). Unlike many previous IO studies of fisheries, this study accounts for the effects of price responses to climate change-driven variations in fish harvest.[3]

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[2] Won is the ROK's monetary unit. Yearly average exchange rate (KRS/dollar) for 2013 was 1,143 KRW per dollar.
(https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates)

[3] Several previous studies recognized the importance of accounting for the responses by the demand side when there is a supply-side shock. For example, Seung and Ianelli (2016) showed that the economic impacts are rather sensitive to the elasticity of world demand for pollock. Moreover, a large number of studies that rely on regression and simulation analysis indicate the importance of considering the responsiveness of prices in estimating the negative effects of climate change-induced impacts on agricultural production. See for example, Deschênes and Greenstone (2007), Schlenker and Roberts (2009), and Miao et al. (2016).

We develop, as the first step, an inter-regional IO model (IRIO) for two regions (GN region and non-GN region) in the ROK. In the second step, a simultaneous equation system (SES) of anchovy supply and demand for GN is estimated to establish and quantify the relationships between anchovy catch, its price, Oceanic Niño Index (ONI), SST, salinity, and household income in the GN region. In the third step, based on these relationships, predictions of the GN's anchovy catch and price are made for the four years under two different greenhouse gas (GHG) concentration scenarios (RCP 4.5 and 8.5)[4]. Finally, we combine the IRIO model with the predictions of the temporal variations in the prices and quantities of raw and processed anchovy obtained in Steps 2-3, and calculate the economic impacts.

The remainder of this paper is constructed as follows. Section 2 presents the IRIO model and the regression model, and discusses the anchovy market in the ROK. Section 3 offers a brief description of the data used. Section 4 presents the results, followed by Section 5 that discusses the results. The final section offers some concluding remarks.

2. Methods

2.1 IRIO model

We use an IRIO model with two regions: the GN province and all non-GN provinces combined, hereafter, the non-GN region. A single-region IO model may be useful in some circumstances. However, if regions in a country are strongly dependent on each other, IRIO or multi-regional IO (MRIO) models are more appropriate, as they can capture the economic effects of a shock to a region that occurs in the other region(s) (spillover effects) and the additional

[4] In Korea, water temperatures of the seas were predicted based on RCP 4.5 and 8.5 scenarios (Kim et al., 2016; NIMF, 2015).

effects on the original region that are engendered due to the spillover effects transpiring in the other region(s) (feedback effects).

This is particularly true for the GN region, which has strong economic linkages with other regions, as evidenced by a previous study (Kim et al. 2017). The GN's seafood industries depend to a great degree on the commodities produced in the non-GN region. Using base-year (2013) data in the IRIO table, which is constructed for this study, we find that, on average, about 48% (in value) of total intermediate inputs used in all GN's raw fish-producing industries (wild fisheries including anchovy fisheries and aquaculture) was from the non-GN region. For the GN's anchovy-catching industry, 31% (in value) of the total intermediate inputs used in the industry was from the non-GN region. These numbers represent a considerable dependence of GN's raw fish production industries on the non-GN's economy. Additionally, GN's reliance on non-GN-produced intermediate inputs (e.g., plastic products and petroleum products) for its fish processing industry is even heavier. For example, in the same year (2013), 55% of the total value of the intermediate inputs used in GN's processing industry was from the non-GN region. As shown below, the strong dependence by GN's seafood industries on the non-GN economy accounts for a large portion of the multiplier effects of GN's anchovy production that are generated in the non-GN region.

Moreover, we use an IRIO model for another important reason; a large share of raw anchovies, once landed in the GN region, is transported to processing facilities in the non-GN region. Data in the IRIO table shows that 18% of the total GN landings of anchovies are shipped to the non-GN region for processing. Therefore, a single-region model for GN cannot correctly estimate the effects of changes in the processing activities in the non-GN region that are caused by variations in the anchovy catch in the GN region.

The remainder of this section briefly outlines the structure of the IRIO model. The IRIO model used in the present study is represented by the equation system below:

$$\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix}, \quad (1)$$

where $\mathbf{X_r}$ (r = 1, 2) denotes the (n x 1) column vector of industry output for region r, where n is the number of industries; $\mathbf{A_{rs}}$ is the (n x n) a matrix that records the transactions of intermediate inputs within a region (when r = s) or between the two regions (when r ≠ s); and $\mathbf{Y_r}$ is the (n × 1) column vector of final demand for industry output produced in region r. The IRIO model can be expressed compactly after solving the equation for $\mathbf{X_r}$ as follows:

$$\boldsymbol{Z} = (\boldsymbol{I} - \boldsymbol{B})^{-1}\boldsymbol{F}, \quad (2)$$

where **Z** is the (2n x 1) vector of industry outputs for the two regions, **B** is the (2n × 2n) matrix of IRIO input coefficients, **F** is the (2n x 1) vector of final demand for the two regions, and $\mathbf{(I\text{-}B)^{-1}}$ is the IRIO multiplier matrix.[5]

2.2 IRIO analysis for the present study

This study distinguishes between two different types of economic impacts: the impacts from quantity change and those from price change. On one hand, impacts from quantity change are produced because of a change in anchovy catch. A change in anchovy catch will alter the anchovy-catching industry's demand for intermediate goods and services (e.g., fuel and repair services) from both the GN and non-GN regions, and will produce multiplier effects throughout the two regions.

[5] Elements of Z, B, and F are given, respectively, as follows. $\boldsymbol{Z} = \begin{bmatrix} X_1 \\ X_2 \end{bmatrix}$, $\boldsymbol{B} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}$, and $\boldsymbol{F} = \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix}$.

On the other hand, impacts from price change are generated through two different ways. First, the increase, for example, in the price of anchovy caused by a reduced level of its catch will increase the income of the fishing-dependent households in GN, and generate some positive economic impacts. Under the two RCP scenarios, the anchovy supply declines because of climate change in some future years, resulting in higher prices for the fish. A higher price means an additional revenue for the lowered level of anchovy catch. This additional revenue will be distributed to factor owners as value-added income, and then to households. Households, now with an increased income, will increase their consumption, generating positive, multiplier effects, and partially counteracting the negative impacts of the reduced supply of fish. Similarly, when the anchovy supply increases, the resulting positive effects will be partially offset by the negative effects of its declining price. Second, the increase in the price means that the anchovy consumers in the whole ROK will have less spendable income available for consumption of non-anchovy goods and services (e.g., recreational activity). This will generate some negative economic impacts. By comparing the impacts from the quantity and price changes, we compute the "net" regional economic impacts.

2.2.1 Revenue decomposition

To compute the economic impacts from price and quantity changes separately, the change in revenue from an altered level of anchovy catch (or anchovy processing) is divided into two parts: the change in revenue from the quantity change and that from the price change. Specifically, let P_0 and P_1 be the ex-vessel prices of raw anchovy before and after the quantity change, respectively. Similarly, let Q_0 and Q_1 be the harvests before and after the quantity change, respectively. Then,

$$P_1Q_1 - P_0Q_0 = P_0(Q_1-Q_0) + (P_1-P_0)Q_1, \quad (3)$$

where $P_0(Q_1-Q_0)$ is the change in revenue from the quantity change measured at P_0, and is given to the IRIO model as a quantity shock; $(P_1-P_0)Q_1$ is the change in revenue from the price change, measured at Q_1, and represents the additional revenue from the price change. The additional revenue $[(P_1-P_0)Q_1]$, after adjusting for indirect business taxes, is distributed to factor owners as factor income. Then, the factor income is adjusted for factor income tax before being distributed to households as household income. Next, the household income is adjusted for individual income tax and savings to obtain the level of additional household spending. Finally, the additional household spending is given as a final demand shock to the IRIO model.

2.2.2 Quantity shock

The aforementioned quantity change (shock) is a supply-side shock, as the shock is given to the supply side, that is, the anchovy *production* (not the final demand for the fish) is exogenously altered due to climate change. We adjust the (originally demand-driven) IRIO model above to accommodate the supply-side shock, and thus, accurately measure its economic impacts. In most economic impact analyses based on IO-type models, the initial shock (direct effect) is considered a demand-side shock (i.e., a change in final demand); thus, one can apply the demand-side shock to the models without making any adjustments.

However, in economic impact analyses for natural resource-based industries (e.g., fisheries, agriculture, forestry, and mining), the initial shock is typically applied to the supply side; for example, an exogenous cut in fish catch due to a decline in total allowable catch (TAC) for a certain species or an exogenous cut in agricultural production arising from a natural disaster. Therefore, following several previous studies (e.g., Seung and Waters, 2013; Seung, 2014; Seung, 2017), we adopt an "adjusted demand-driven modeling" approach. In this approach, the regional purchase coefficients (RPCs) for raw fish production and seafood processing industries are set to zero before incorporating the exogenous shock (i.e., the change in anchovy catch in this study) into the model as a final demand shock. Details on this approach are found in Seung and Waters (2013) and Seung (2014, 2017).

2.2.3 Final demand shocks

There are two different types of final demand shocks considered in this study. Both types of shocks occur due to a change in the prices of raw and processed anchovy. The first type of shock (Type 1 final demand shock, Type 1 FD shock, hereafter) is the change in the spending by the fishing-dependent households in GN. The second type (Type 2 FD shock, hereafter) is the change in all ROK households' spending on non-anchovy commodities.

When the anchovy price changes in response to a change in its quantity, it is assumed for Type 1 FD shock that all of the resulting changes in the anchovy harvesters' and processors' revenues from the after-quantity-change level of anchovy harvest will be distributed to the factor (labor and capital) owners, and then to households. This is a reasonable assumption because it is likely that intermediate inputs are used in proportion to the level of fish harvest, not the level of revenue. Thus, with the quantity of anchovies fixed at the after-quantity-change level, the change in the anchovy price and the resulting change in revenue are not likely to prompt an additional change in the intermediate input use beyond the change attributable to the quantity change. Thus, the additional revenue (change in the household income) will be spent on goods and services, counteracting the effects of the quantity change to some extent. Since households consume a variety of commodities, we allocate the additional household income to 161 different commodities, produced by the corresponding 161 industries in the IRIO model, based on the base-year household expenditure coefficients for GN and non-GN households. We obtain two different sets for GN and non-GN households' expenditures, which are then applied to the IRIO model as final demand shocks.

For Type 2 FD shock, we assume that the disposable income of ROK households is fixed, and their anchovy consumption is fixed. Based on these assumptions, we calculate the change in the expenditure by people in ROK on non-anchovy commodities, allocate the change across the 161 different industries, and administer Type 2 FD shock.

2.3 Estimating anchovy supply and demand

We estimate an SES for GN consisting of anchovy supply and demand functions using a two-stage least squares (2SLS) regression technique.[6] Previous studies indicate that SST is the most important environmental variable that directly affects the anchovy catch while ONI and salinity are the environmental variables that may indirectly affect the catch (Lee and Kim 2007 and Eom et al., 2015). Thus, the supply function is estimated as follows:

$$Y_t = C + a_1 ONI_t + a_2 SST_t + a_3 SAL_t + a_4 P_t \quad (4)$$

where Y = anchovy catch (mt)

C = constant

ONI = oceanic niño index (°C)

SST = sea surface temperature (°C)

SAL = sea water salinity (psu)

[6] A few studies have used an SES approach in which both the demand and supply are modeled as endogenous variables (e.g., Herrmann and Criddle, 2006; Strong and Criddle, 2014; Warpinski et al., 2016) for estimating the seafood market.

P = anchovy price (thousand Won / mt)

t = year t

a's = coefficients.

The time series data for these variables are obtained for the period (2006-2019). The ONI is US National Oceanic and Atmospheric Administration (NOAA)'s primary indicator for monitoring El Niño and La Niña, which are opposite phases of the climate pattern called the El Niño-Southern Oscillation. It tracks the rolling 3-month average SSTs in the east-central tropical Pacific. When the index is 0.5°C or higher, El Niño conditions exist, indicating that the east-central tropical Pacific is significantly warmer than usual (NOAA, 2018). Data on ONI are obtained from the NOAA Climate Prediction Center (NOAA, 2018), and data on SST and SAL (Salinity) are obtained from the NIFS Oceanographic Data Center (NIFS, 2018).

Anchovy demand function is estimated as follows.

$$P_t = C + b_1 Y_t + b_2 INC_t \quad (5)$$

where P = anchovy price (thousand Won / mt)

Y = anchovy catch (mt)

INC = per capita disposable income (ten thousand Won)

C = constant

t = year t

b's = coefficients.

We include anchovy catch (Y, mt) and market price (P, thousand Won/mt) both in the supply and demand equations, in order to estimate the SES for GN. We apply GDP deflator (2015=100) to both the price and household income (INC) variables.

2.4 ROK anchovy market

The ROK anchovy market is unique in several respects. First, on the supply side, anchovy fishermen in the country can hardly diversify the species they catch because the gear they use (mostly anchovy drag net) is designed for anchovy catch only. This means that a higher price, for example, for other species, will not likely trigger the anchovy fishermen to switch to this species. Additionally, almost all anchovies caught in the ROK are either dried or salted before human consumption in the country. Moreover, the global market share of ROK's anchovy imports is negligible (FIPS, 2020). For instance, the very small quantity of anchovies imported from Peru is ground, and then used as animal or fish farming feed, but not for human consumption.

Second, on the demand side, anchovy consumption in the ROK is not affected by the prices of other fish or meat because anchovy is not a substitute for these alternative sources of protein. Salted anchovy is an essential ingredient / condiment in making Kimchi while dried anchovy is used to make anchovy broth that forms the basis of different kinds of soups and stews in Korea. No other species can replace anchovy for these purposes. Furthermore, anchovy cannot replace other fish species that are usually eaten raw or grilled. As in the case of imports, the global market share of the ROK's anchovy exports is also insignificant (FIPS, 2020). These unique features imply that the ROK's anchovy market is nearly isolated from the global market, and that the prices of raw and processed anchovies are determined primarily by their domestic supply and demand.

Predictions for the future prices of processed anchovies are made as follows. Based on the data (KOSIS, 2020b) on the quantity of, and revenue from, seafood processing by product type and species, we first calculate the prices of dried and salted anchovies. Then, we compute the weighted average of the two prices, where the weights are the ratios of the revenues from the two products to the combined revenue for the total anchovy processing. Next, we estimate the ratio (3.94) of the weighted average of the prices obtained to the price of the raw anchovy. Finally, this ratio is multiplied by the base-year price of the raw fish and by each of its future prices to compute the prices of the processed anchovy in the future years.

3. Data

To develop the IRIO model, this study uses the 2013 MRIO table, which identifies 161 industries separately, for 16 provinces in the ROK (Bank of Korea (BOK), 2015), one of which is the GN province. The MRIO table includes information on the transactions transpiring within a province and among the 16 provinces in the ROK. Then, the 15 non-GN provinces are combined into a single region while keeping the GN province as a separate region, resulting in a two-region IRIO table.

The original 161-sector MRIO data have only two seafood industries as separate industries: raw fish production and seafood processing. To study the economic impacts of climate variation on anchovy, we divide the single raw fish production industry into three smaller industries: anchovy harvesting, non-anchovy harvesting, and aquaculture. We use, for both GN and non-GN regions, (i) the 2010 MRIO dataset that provides information on the production functions for wild fisheries and aquaculture separately; (ii) production and revenue information (KOSIS, 2020a) for the three raw fish production industries (anchovy fishery, other wild fisheries, and aquaculture); and (iii) cost information for various vessel types (gear types) from the National Federation of Fisheries Cooperatives (2014). Additionally, we modify the seafood processing data in the IRIO table using these data (KOSIS, 2020b). As mentioned, to obtain the price projections for the processed anchovy, this study relies on the seafood processing data (KOSIS, 2020b) and the price projections for the raw fish obtained using Equations (4) and (5).

For Type 1 FD shock, this study estimates the changes in fishery-dependent households' spending induced by variations in anchovy price by utilizing the 2013 MRIO data (BOK, 2015) to obtain the ratios of total factor income to the total value-added income for the GN's fish harvesting (0.75) and processing (0.73) industries and non-GN processing industry (0.72). Finally, the average income tax rate (4.3%) and savings rate (39.4%) for ROK households are obtained from Lee et al. (2014). To derive Type 2 FD shock, we use 2013 IRIO data that indicate (i) that 46% of total GN's production of seafood is used for final consumption with the remainder used as intermediate inputs, (ii) that 28% of GN-produced seafood is consumed by GN residents, and (iii) that only 90% of the extra spendable income available from a lower anchovy price is spent on the non-anchovy commodities produced in ROK with the remainder spent on imports.

4. Results

4.1 Results from regression analysis

Descriptive statistics on the data used to estimate the SES are provided in Table 1. Table 2 presents results from the regression analysis for the anchovy supply function. The table shows that the model fit is statistically significant, and that a strong relationship exists between anchovy catch and SST with its p-value equal to 0.068. The signs of the coefficients for all the explanatory variables are all negative as expected, meaning that the anchovy catch decreases as the variables increase, although only the coefficient for SST is significant. Table 3, which reports the estimated coefficients for the demand function, indicates that the model fits the data well, and that price has strong relationship with anchovy catch and household income with the p-values of the two explanatory variables being less than 0.005.

Using the supply and demand equations estimated as above, we conduct a sensitivity analysis for the parameters in the equations. Specifically, we first calculate the change in the two endogenous variables (Y and P) from a 5% increase in SST. When SST increases 5%, anchovy catch decreases by 31,513 mt while the price goes up by 232 thousand Won, when computed with all the parameter values at their original levels. Next, we examine how the *change* in these two variables varies when we increase each of the model parameters, one at time, by 5%. Results are presented in Table 4. In the table, each number in the third column represents *variation* in the *change* in Y as a percentage of the variable's baseline value (i.e., the average value in Table 1). The table indicates, for instance, that the impact of a 5% increase in SST on Y is larger by 0.0007% with a higher value of a1 (1.05 * original value of a1) than with its original value, whereas the impact on P is smaller by 0.0005% with the higher value of a1 than with its original value. Results indicate that the impacts of a 5% increase in SST on the endogenous variables are rather sensitive to the variation in the coefficient for SST (a2) with the percentage variations being -26.8% and 18.7%, respectively, for the two endogenous variables. The impacts of SST are also sensitive to the variation in the coefficient for salinity (SAL) (a3) with the percentage variations being -12.9% (Y) and 9.0% (P), respectively. Results from this sensitivity analysis suggest that it is important to estimate correctly the two coefficients (a2 and a3) since results are sensitive to these two coefficients.

4.2 Predictions of anchovy catch and processing

Based on the results in Tables 2 and 3 and the two RCP scenarios, this study derives the trajectories of average monthly anchovy catch over the four years for the whole ROK (not shown in the present paper, but available upon request). Using these trajectories, we obtain (i) the projections of both the *annual* production of the raw fish and its annual price for the GN region under the two GHG concentration scenarios; and (ii) similar projections for the processed fish for the GN region and the non-GN region (Table 5).[7]

Anchovy catch for the base-year (2013) was 122,067 mt. As seen in Table 5, under the RCP 4.5 scenario, GN's anchovy catch is lower in 2020 and 2050, with 110,674 and 110,295 mt, respectively, than in the base year. In percentage terms, the harvests in 2020 and 2050 are 9.3% and 9.6% lower than the base-year level, respectively. In the other two future years (2030 and 2100), the harvests are higher with 133,422 mt and 144,645 mt, respectively, than in the base year. Further, changes in the levels of anchovy processing in the two regions follow similar trends.[8] As expected, the price and quantity of raw anchovy move in opposite directions; when the anchovy catch increases, the price decreases (Table 5). Similarly, the price and quantity of processed fish in the two regions move in opposite directions.

Table 5 shows that under the RCP 8.5 scenario, the climate impacts on the anchovy harvest in GN region are more severe than under RCP 4.5. Whereas the anchovy catch under RCP 4.5 fluctuates over the years, the catch under RCP 8.5 steadily falls from 126,234 mt in 2020 to 100,322 mt in 2050 with a steady rise in price. After 2050, the catch plummets dramatically reaching 31,589 mt in 2100, with the price surging rapidly. This dramatic change in

[7] For those who are interested in the visual presentations of the results in Table 5, the Appendix provides several figures.
[8] Changes in the level of the non-GN region's anchovy processing occur because of fluctuations in the GN region's anchovy harvest. Some of this harvest is transported to the non-GN region's processing plants for processing.

the predicted quantity and price of fish in 2100 represent values that are 74.1% lower and 40.1% higher, respectively, than their base-year levels (Table 5). The averages of the absolute values of the percentage changes (over the years) in the price of the raw fish were 8.4% and 13.6%, respectively, under RCP 4.5 and RCP 8.5, while the averages for the quantity of the fish were 11.9% and 26.9% under the two RCP scenarios, respectively.

4.3 Economic impact results

Based on the data in Table 5, the economic impacts are calculated. For a given year (2020, 2030, 2050, or 2100), the quantity shock (direct effect) for the anchovy-harvesting industry, which is applied to the IRIO model, is defined as the difference between the level of anchovy catch in the year and its base-year level. Similarly, the quantity shock for the processing industry is defined as the difference between the level of anchovy processing in the year and its base-year level. As described in Section 2.2, we apply two different types of final demand shock – Type 1 FD and Type 2 FD shocks. Type 1 FD shock is defined as the change in the spending by fishery-dependent households. Type 2 FD shock is defined as the change in the spending by all households in ROK.

Table 6 presents the economic impact results. In 2020, under RCP 4.5, without considering the price responses (Columns 4-6), the total regional outputs (sales) in the GN and non-GN regions decline (from their 2013 levels) by 30,778 and 16,306 million Won, respectively, with the overall decline in the ROK amounting to 47,085 million Won. When the change in the fishery-dependent households' spending from the price change is considered (Columns 7-9), the total output in the two regions decreases further so that the total output in the country declines by 49,044 million Won. This occurs because the price of raw anchovy (1,405 thousand KRW), which is predicted using the anchovy supply and demand functions, is lower than its base-year level (1,418 thousand KRW), and the predicted quantity (110,674 mt) is also smaller than its base-year level (122,067 mt). Lower anchovy price means that the fishery-dependent households' spending will decrease, exacerbating the negative impacts of reduced anchovy catch.

The lower anchovy price also means that households in ROK will spend less on anchovy products, but more on non-anchovy commodities (e.g., spending on recreation). This additional spending will offset to some degree the negative impacts of the decrease in both the price and quantity of anchovy, resulting in the net negative impacts on total ROK output now becoming smaller (47,073 million Won, Column 12).

In 2030, harvest of raw anchovy increases by 10.1%, whereas its price drops by 13.3% (Table 5). In that year, the total ROK output from the quantity shock increases by 51,060 million Won (Column 6, Table 6). However, the decrease in the price has negative effects on the fishery-dependent households' income, and offset considerably the positive effects of the quantity shock with the increase in the ROK output totaling only 16,630 million Won (Column 9). Lower anchovy price, however, causes the ROK households to spend more on non-anchovy commodities, leading to the net impacts on the total ROK output being 51,261 million Won (Column 12). Results for years 2050 and 2100 under RCP 4.5 exhibit patterns similar to those for years 2020 and 2030, respectively, with only the magnitudes of the impacts being different.

Under RCP 8.5, changes in the price and quantity over the years, on average, are much larger than under RCP 4.5, with the most extreme case being in 2100. In that year, the anchovy harvest in the GN region plummets by 74.1%, whereas its price rises by 40.1%. Under RCP 8.5, the prices of both raw and processed fish rise continuously from 2030 (Table 5). The effects of the higher prices on the fishery-dependent households' income partially offset the negative impacts of the reduced harvests. In 2030, for example, considering only the quantity shock, the total ROK output decreases by 61,053 million Won. Taking into account the effect of increased spending by the fishery-dependent households, the total ROK output decreases by less (59,298 million Won). The reduced spending by the ROK households from the higher prices causes the quantity of reduction in the total ROK output to become larger (61,063 million Won). Similar pattern of results is observed for the other two years (2050 and 2100). (Table 6).

Table 7 presents the offsetting effects from the two different types of final demand shocks as a percentage of the economic impacts computed with only the quantity change. The offsetting effects are shown to be remarkable. The largest offsetting effects of Type 1 FD shock for ROK are observed for 2030 (67.4%) under RCP 4.5 and for 2020 (127.8%) under RCP 8.5 (Columns 2-4). The average of the offsetting effects of Type 1 FD shock for the entire ROK across the four future years and the two RCP scenarios is 32.8% (not shown in Table 7).

Columns 5-7 show the offsetting effects of the two types of shocks combined. Notably, when the quantity increases substantially, and the price decreases drastically as a result (years 2030 and 2100 under RCP 4.5 and year 2020 under RCP 8.5), the offsetting effects of Type 2 FD shock on non-GN's output are so large that the resulting final impacts on non-GN's output are significantly larger than the impacts from the quantity shock only. For instance, in 2100 under RCP 4.5, the net impacts on non-GN's output from the quantity shock and Type 1 FD shock combined are 11,984 million Won (Column 8, Table 6), and the offsetting effects of Type 1 FD shock are 62.9% (Column 3, Table 7) of the impacts calculated with the quantity shock only (32,315 million Won, Column 5, Table 6). Results indicate that the effects of Type 2 FD shock more than compensate for the negative effects of Type 1 FD shock so that the final impacts

(53,109 million Won, Column 11, Table 6) are significantly larger (64.3% larger, Column 6, Table 7) than the impacts from quantity change only (32,315 million Won, Column 5, Table 6).

An interesting result is that the national-level offsetting effects (Column 7, Table 7) of the two types of final demand shocks combined are very small (less than 1% of the impacts from quantity shock only). This means that the offsetting effects of the two types of final demand shocks roughly cancel each other out at the national level, although the effects may be drastically different between the two regions.

5. Discussion

Although numerous studies have explored the economic impacts of climate change on non-seafood industries[9], relatively few have examined its economic impacts of climate change-induced variations in fisheries. Arnason (2007) estimated the dynamic economic effects of fluctuations in fish populations caused by warmer seawater temperatures for two countries (i.e., Greenland and Iceland). Interestingly, he found that the fishing activities in the two countries increased due to the higher temperatures, resulting in higher gross domestic products (GDPs). The study, however, had a limitation as it assessed the impact on only one economic variable (i.e., GDP).

Some studies relied on input-output (IO) models. Cooley and Doney (2009), for instance, quantified the change in the total US industry revenue resulting from decreased mollusk populations brought about by ocean acidification (OA), finding that a 10–25% cut in mollusk harvest from the 2007 level would reduce the total US industry revenue by USD 75–187 million. Norman-Lopez et al. (2011) also used an IO model to assess the economic effects of climate

[9] For a review of these studies, see Tol (2009).

change on Australian marine fisheries, showing that most fishery and non-industry sectors in the country would actually benefit from climate change.

Similarly, Narita et al. (2012) investigated the economic effects of lowered levels of mollusk harvest from OA using diverse assumptions about the change in mollusk demand. They found that the world economy would incur an economic cost between USD 6 to 100 billion, depending on the assumptions about the mollusk demand.

Several studies have evaluated the adverse impacts of climate change on Alaska fisheries. Seung et al. (2015) combined a bioeconomic model for the Bristol Bay red king crab (BBRKC) fishery with a dynamic computable general equilibrium (CGE) model to compute the regional economic impacts of OA-induced variability on fishery yields. They found that economic impacts are sensitive to the forms (linear vs. nonlinear) of OA effects on the survival of juvenile BBRKC and to the variations in the world price of BBRKC. In contrast, Seung and Ianelli (2016, 2019) integrated a temperature-sensitive biological stock-yield projection model for the eastern Bering Sea pollock with a CGE model to quantify the adverse economic effects of lowered levels of pollock catch due to rising SST. Similar to Narita et al. (2012), Seung et al. (2015) and Seung and Ianelli (2016) considered different assumptions about world demand for Alaskan fish (BBRKC or Pollock) to estimate the economic impacts.

More recently, several projects funded by the European Union investigated the impact of climate change under the two IPCC scenarios (RCP 4.5 and RCP 8.5) on fisheries and aquaculture. Examples include ClimeFish project (https://climefish.eu) and Ceres project (https://ceresproject.eu/).

Some of these studies [Cooley and Doney (2009) and Norman-Lopez et al. (2011)] used an IO model for a national economy [US in Cooley and Doney (2009) and Australia in Norman-

Lopez et al. (2011)] while the present study applies an IRIO model to a *regional* economy. Other studies [Seung et al. (2015) and Seung and Ianelli (2016)] combined a regional economic model [a regional computable general equilibrium (CGE) model] with a biological model. These two studies were for a sub-national region (Alaska) as in the present study. In these two studies, as in the present study, the effects of price change are accounted for, but in a different way. While these two previous studies used a modeling framework (CGE) that allows endogenous determination of all the prices, the present study allows only the price of anchovy to be endogenous, assuming that the prices of all the other commodities are fixed. However, an advantage of the present study over these two previous studies is that the present study estimates the anchovy market specifically for the region of interest (GN) using regression analysis whereas these two previous studies borrowed from earlier studies the values of important parameters that govern the behavior of the relevant seafood markets [crab market in Seung et al. (2015) and Alaska pollock market in Seung and Ianelli (2016)].

The present study considers three different types of shocks given to the IRIO model. These shocks are quantity shock, shock to fishery-dependent households' spending (Type 1 FD shock), and shock to the spending by all ROK households (Type 2 FD shock). The latter two shocks are considered because the price of anchovy changes in response to a change in its quantity. Results from the present study indicate that the regional-level (i.e., GN and non-GN) economic impacts of variations in SST in ROK waters calculated with both quantity and price changes are considerably different from those calculated with the quantity change only. This study shows that failure to account for the price effects will lead to biased estimates of the economic impacts when the quantity changes are substantial.

When assessing the impacts of variations in fisheries, fishery analysts who use IO-type models often do not account for the price effects due to several reasons. First, the fundamental assumption underlying the IO models is that all prices are fixed. Second, even though analysts may feel the need to consider the effects of price change, information about the responsiveness of prices may not exist for their study regions.

The present study first estimates the relationships among anchovy catch, its price, household income, and environmental variables that serve as indicators of climate change within an SES consisting of both anchovy supply and demand functions using 2SLS technique. Next, this study uses the estimated relationships to derive projections of the future prices and quantities of both raw and processed anchovy. By accounting for the price responses, this study can make a more accurate assessment of the economic impacts of climate variation. In line with the fundamental assumption of IO models, many previous IO analyses of fisheries implicitly assumed that the prices of raw and processed fish are fixed, and thus, treated the change in ex-vessel and ex-processor revenues from changes in fish production as the initial shock to an IO model.

When the price does not change substantially following a quantity shock, using the revenue change as the initial shock (direct effect) may not bias the results significantly. However, when the price change is drastic, as in this study, using the revenue change as the initial shock will produce highly biased results. This is because the portion of the revenue change accounted for by the price variation will only alter value-added income (and then household income) rather than changing the intermediate input use.

The present study has an important implication for regional-level fishery managers who are often not aware of the effects of price responses that can counteract the negative impacts of cuts in fish production caused by climate change or other external policy shocks. They may be shocked at the magnitudes of the economic impacts computed without considering the price effects, as shown in Tables 5, 6, and 7. The present study, however, clearly illustrates that the economy-wide negative impacts can be much smaller than they think if the price responses are taken into account. In addition, this study finds that the two types of final demand shocks roughly cancel each other out at the national level, although the offsetting effects may be drastically different between the two regions. This finding may be useful to national-level policy makers who are concerned about the national-level economic impacts.

In this study, the large offsetting effects from price variations are most likely due to the isolation of the anchovy market in the ROK from the global market, which reduces the effects of the world anchovy market. As mentioned, the imported anchovies are not used for human consumption in the ROK. However, if the anchovies available in the world market were a good substitute for the ROK-produced anchovies, the large offsetting effects shown in this study would not be obtained because the imported fish would alleviate the anchovy shortage from climate change in the country, and consequently, the price would not increase as sharply as in this study.

One caveat related to the responsiveness of price to quantity change is the assumption used in this study that there is a linear relationship between price and quantity in the demand equation. Due to this assumption, the price response from a large change in the quantity may be biased, depending on the year and the RCP scenario. Therefore, the offsetting economic impacts from the two types of final demand shocks may be over- or underestimated to some degree.

Our study combines an econometric model with an IO model, and conduct a relatively simple sensitivity analysis for the coefficients in the econometric model. This type of sensitivity analysis is local in the sense that the analysis is carried out for only a subset of all the parameters in our combined econometric-IO model. However, uncertainty may arise not only from the econometric model but also from the IO model. First, the uncertainty associated with the IO coefficients arise, among other things, due to the fact that the IO data are often obtained via surveys, meaning that the data are subject to sampling errors. In addition, the IO data are vulnerable to measurement errors, compilation errors, aggregation errors, and reporting errors. Furthermore, if the IO data contains inter-regional or multi-regional data covering more than one region as in our study, the data suffers from additional types of errors such as inconsistency among different regions in the definitions of industries / commodities and errors associated with the measurement of inter-regional trade flows. [Kop Jansen 1994, ten Raa and Steel 1994, and Temurshoev 2007).

Our study does not conduct sensitivity analysis for the IO model. However, a global sensitivity analysis where all the parameters / coefficients from the two different models (the econometric model and the IO model in our study) are simultaneously perturbed warrants a separate research in the future. That research will provide information about the range of the economic impacts from climate change.

IO models assume that all the prices are fixed. Due to this assumption, IO models cannot examine substitution effects and welfare effects. Although we allow the price of anchovy to vary in its supply and demand functions, we do not allow the prices of non-anchovy commodities to change. The assumption that the prices of non-anchovy commodities do not vary may be acceptable in this study in the following respect. The anchovy industry is a very small portion of the regional economy. Therefore, a shock given to the industry may not lead to a significant change in the prices of non-anchovy commodities (e.g., automobiles). As a result, the substitution effects occurring from the change in the relative prices of all these commodities may be relatively small. If the price changes were significant, however, one would need a computable general equilibrium (CGE) which allows prices to vary and substitution effects to occur.

This study assumes that a higher price of a non-anchovy species will not likely trigger the anchovy fishermen to switch to this species, implying that the capital (vessels and equipment) used in the anchovy fishery will not move to the non-anchovy fishery. We adopt this assumption for two reasons. First, a typical anchovy fishing fleet in ROK consists of two fish-catching vessels, one fish-searching vessel, one fish-processing vessel, and two fish-transporting vessels. Further, almost 99% of anchovy catch in ROK is made by anchovy drag net vessels. Transforming the capital in the anchovy fishery to the capital in a non-anchovy fishery will involve selling the capital goods in the anchovy fishery and buying new capital goods for the non-anchovy fishery. This process may take an unusually long time. Second, more importantly, if an anchovy fisherman (fishing vessel owner) wants to enter a non-anchovy fishery, the fisherman will have to obtain a permit from the government. However, since it is now a government policy to reduce the fishing capacity across all the fisheries, the government will not issue a permit to the new entrant unless the new entrant replaces a permit holder in the non-anchovy fishery or some of the existing permit holders in the non-anchovy fishery retire. Therefore, it seems reasonable to assume that capital does not move from anchovy fishery to non-anchovy fisheries.

The economic impacts of climate variation in this study are measured in terms of the changes in only one economic variable, total industry output, to illustrate how the net economic impacts gauged by the variable change over time depending on different RCP scenarios, rather than reporting the impacts on all the regional economic variables. It will be straightforward, however, to extend the analysis and compute the impacts on other variables such as employment and value-added, although it does not seem likely that the additional computations will provide any additional implications that are meaningful to fishery managers.

The present study has a limitation. It focuses on the GN region's anchovy, implicitly assuming that the rising SST will not affect other species. In reality, however, the whole marine ecosystem in Korean waters will be disturbed by climate change, resulting in variations in the biomasses and harvests of different fish species. Anchovy is at a relatively low trophic level in the marine ecosystem, being preyed on by many other fish species at higher levels. Therefore, variations in the level of the anchovy biomass and its harvest will have considerable impacts on the marine ecosystem in Korean waters.

Decrease in anchovy biomass will lower the population of the species that prey on anchovy, and therefore, their harvest. However, it is unknown how and to what extent the variations in the anchovy biomass affect the biomass and catch of other species. Since climate change may affect other species too and each species may respond differently to the climate change, it will be difficult to understand how the climate change will affect other species without information from a marine fishery food web models such as Ecosim or Ecopath. Depending on how other species responds to changes in climate and biomass of anchovy, the economic impact results in this study may be over- or under-estimated. Since there are no studies that examined how the harvests of different species would change due to climate change, this study is restricted to anchovy.

6. Concluding remarks

Climate change affects productivity and harvest of fish, and has impacts on fishery-dependent economies. When calculating the economic impacts, however, analysts often consider only the change in quantity (harvest). To overcome this weakness, this study takes into account both the quantity change and the price response, and evaluates the net economic impacts of climate-driven change in GN's anchovy fishery for two different regions in ROK. We find that the offsetting effects of the price responses are substantial at regional level. An interesting finding is that the offsetting effects of the two different final demand shocks on the whole ROK economy roughly cancel each other out. These findings would not be obtained if the price effects were not taken into account. Policy makers will find these findings useful.

This study can be extended in two directions. First, a full-scale sensitivity analysis will be useful in order to find the range of economic impacts of climate change. As discussed above, the economic impacts are subject to the uncertainty associated with the parameters in the SES and the IO coefficients. In our study, a simple local sensitivity analysis is performed by varying the parameters from the regression model. A future study can carry out a global sensitivity analysis in which both the parameters from the regression model and the IO coefficients are allowed to vary simultaneously. Second, developing a CGE model for GN's anchovy fishery will be a useful task because the CGE model overcomes the limitations of our study, that is, the inability of IO models to allow flexible prices and substitution effects. Once developed, the CGE model will be able to calculate the welfare effects of climate change-induced impacts on GN's anchovy fishery as well as the effects on other economic variables.

Funding

This work was supported by grant from the National Institute of Fisheries Science (R2020031).

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Table 1 Descriptive statistics on variables used in 2SLS (N = 14)

Variable	Average	Standard Deviation	Min	Max
Catch (mt)	123,403	20,876	84,150	148,164
Temperature (℃)	18.68	0.49	17.62	19.48
Salinity (psu)	33.23	0.34	32.45	33.65
ONI (℃)	-0.03	0.51	-0.73	1.25
Price (thousand Won/mt)	1,302	224	1,014	1,632
Per capita disposable income (10 thousand Won)	1,622	271	1,201	2,026

Table 2. Results from 2SLS regression for anchovy supply

Variable	Coefficient	Std. Error	Prob.
Constant	885,858.8	630,299.4	0.160
ONI (℃)	-445.7	10,076.9	0.965
SST (℃)	-25,644.1	14,050.5	0.068
SAL (psu)	-7,251.7	13,598.9	0.594
P (thousand Won/mt)	-32.6	42.2	0.440
Wald chi2(4) = 48.5, Prob > chi2 = 0.0000, R-squared = 0.7827, N = 14			

Table 3. Results from 2SLS regression for anchovy demand

Variable	Coefficient	Std. Error	Prob.
Constant	1,632.8	364.8	0.000
Y (mt)	-0.00736	0.00177	0.000
INC (10 thousand Won)	0.3559	0.1186	0.003
Wald chi2(4) = 58.9, Prob > chi2 = 0.0000, R-squared = 0.8035, N = 14			

Table 4 Sensitivity of endogenous variables to change in parameters (%)

Exogenous variable	Coefficients	% variation in Y	% variation in P
ONI (℃)	a1	0.0007	-0.0005
SST (℃)	a2	-26.8	18.7
Salinity (psu)	a3	-12.8	9.0
P (thousand Won/mt)	a4	-2.7	1.9
Y (mt)	b1	1.2	-3.5
INC (10 thousand Won)	b2	-1.0	2.9

Table 5. Predictions of anchovy harvest and prices under two RCP scenarios

RCP 4.5					
	base year	2020	2030	2050	2100
GN's anchovy harvest (mt)	122,067	110,674	134,422	110,295	144,645
GN's anchovy price (per mt, thousand won)	1,418	1,405	1,230	1,408	1,155
GN's anchovy processing (net weight, mt)	18,053	16,368	19,880	16,312	21,392
Price of processed anchovy (per mt, thousand won)	5,587	5,536	4,846	5,548	4,551
Non-GN's anchovy processing (net weight, mt)	8,293	7,519	9,132	7,493	9,826
% change in GN's anchovy catch		-9.3	10.1	-9.6	18.5
% change in GN's anchovy price		-0.9	-13.3	-0.7	-18.5
RCP 8.5					
	base year	2020	2030	2050	2100
GN's anchovy harvest (mt)	122,067	126,234	107,294	100,322	31,589
GN's anchovy price (per mt, thousand won)	1,418	1,290	1,430	1,481	1,987
GN's anchovy processing (net weight, mt)	18,053	18,669	15,868	14,837	4,672
Price of processed anchovy (per mt, thousand won)	5,587	5,083	5,634	5,835	7,829
Non-GN's anchovy processing (net weight, mt)	8,293	8,576	7,289	6,815	2,146
% change in GN's anchovy catch		3.4	-12.1	-17.8	-74.1
% change in GN's anchovy price		-9	0.8	4.4	40.1

Table 6. Economic impacts of climate change under two RCP scenarios by region

	Predictions of price and catch of GN's anchovy		With quantity shock only (million Won)			With quantity shock and Type 1 FD shock (million Won)			With quantity shock and Type 1 and Type 2 FD shocks (million Won)		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Year	Catch (mt)	Price (thousand Won per mt)	GN	Non-GN	TOTAL	GN	Non-GN	TOTAL	GN	Non-GN	TOTAL
RCP 4.5											
2020	110,674	1,405	-30,778	-16,306	-47,085	-31,969	-17,075	-49,044	-31,553	-15,520	-47,073
2030	134,422	1,230	33,377	17,683	51,060	12,453	4,177	16,630	19,764	31,497	51,261
2050	110,295	1,408	-31,802	-16,849	-48,651	-32,715	-17,438	-50,153	-32,396	-16,246	-48,642
2100	144,645	1,155	60,995	32,315	93,309	29,497	11,984	41,480	40,503	53,109	93,611
RCP 8.5											
2020	126,234	1,290	11,257	5,964	17,221	-2,121	-2,671	-4,792	2,553	14,796	17,349
2030	107,294	1,430	-39,909	-21,144	-61,053	-38,843	-20,455	-59,298	-39,216	-21,848	-61,063
2050	100,322	1,481	-58,744	-31,122	-89,867	-53,511	-27,744	-81,255	-55,340	-34,578	-89,917
2100	31,589	1,987	-244,428	-129,496	-373,924	-229,545	-119,890	-349,435	-234,745	-139,321	-374,066

Table 7. Offsetting effects of two final demand shocks under two RCP scenarios by region (%)

	Type 1 FD shock			Type 1 plus Type 2 FD shocks		
	GN	Non-GN	TOTAL	GN	Non-GN	TOTAL
RCP 4.5						
2020	3.9	4.7	4.2	2.5	-4.8	-0.02
2030	-62.7	-76.4	-67.4	-40.8	78.1	0.39
2050	2.9	3.5	3.1	1.9	-3.6	-0.02
2100	-51.6	-62.9	-55.5	-33.6	64.3	0.32
RCP 8.5						
2020	-118.8	-144.8	-127.8	-77.3	148.1	0.74
2030	-2.7	-3.3	-2.9	-1.7	3.3	0.02
2050	-8.9	-10.9	-9.6	-5.8	11.1	0.06
2100	-6.1	-7.4	-6.5	-4.0	7.6	0.04

Appendix: Projections of prices and quantities of raw and processed anchovies under two RCP scenarios

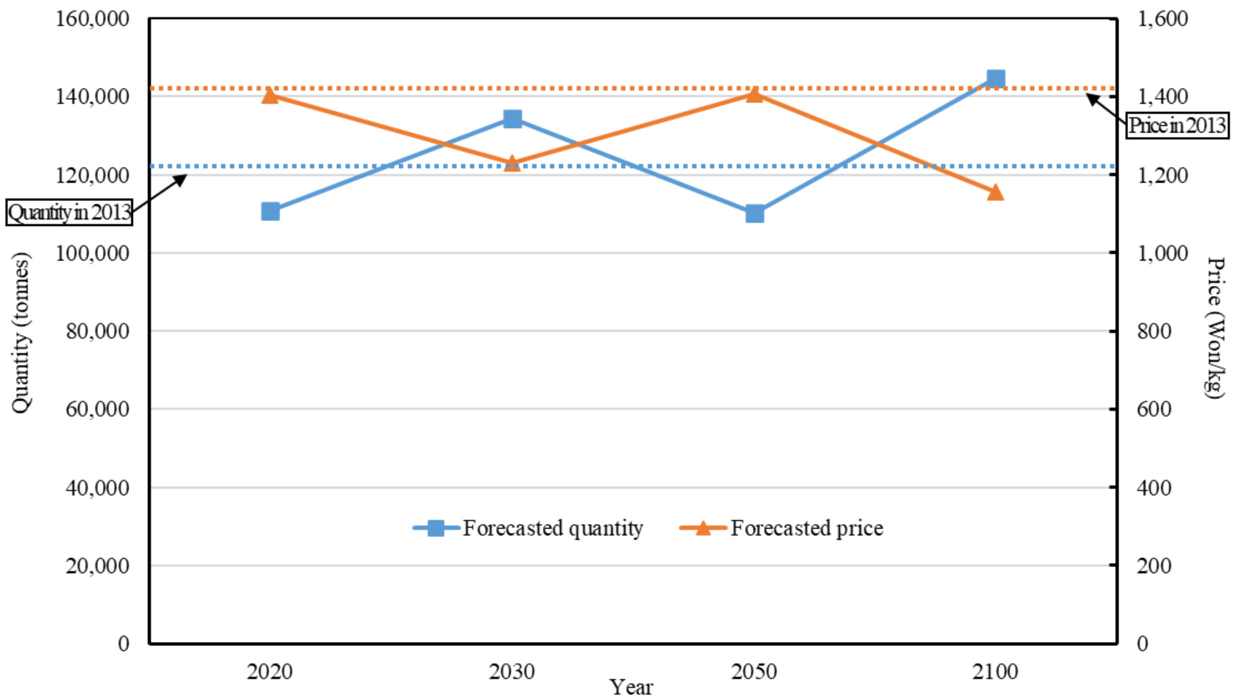

Figure A1. Projections of price and quantity of raw anchovies under RCP 4.5 for GN province

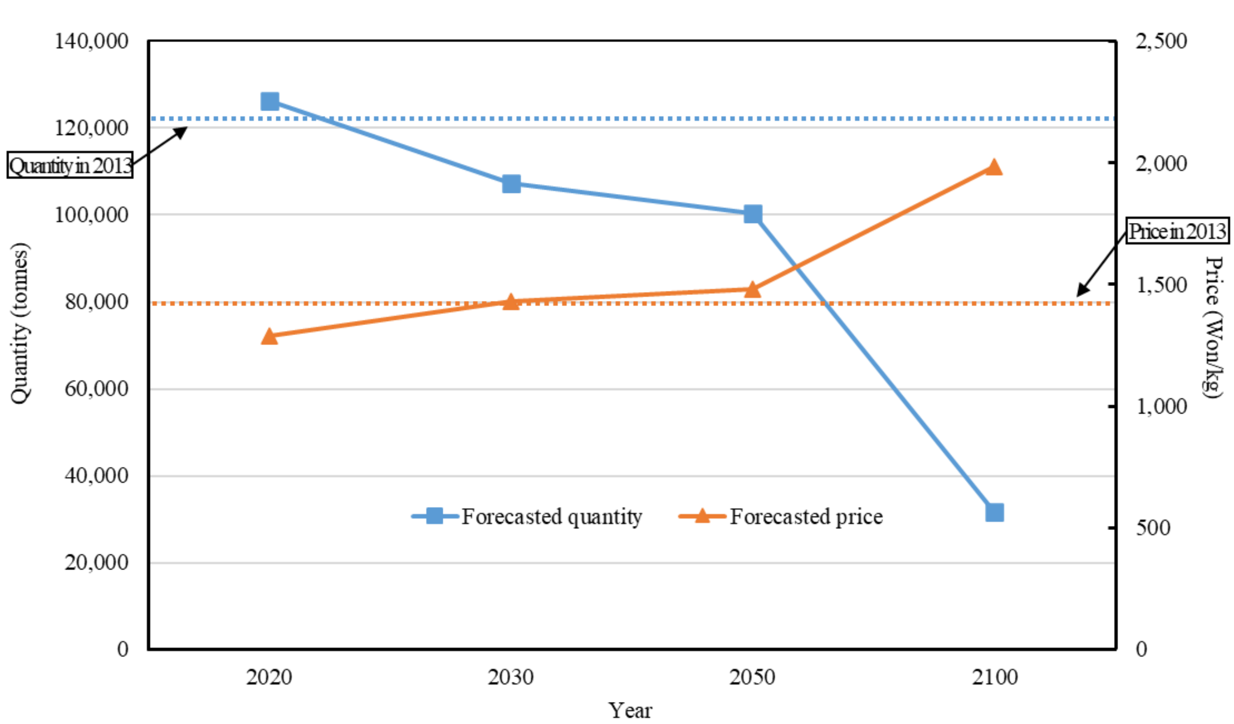

Figure A2. Projections of price and quantity of raw anchovies under RCP 8.5 for GN province

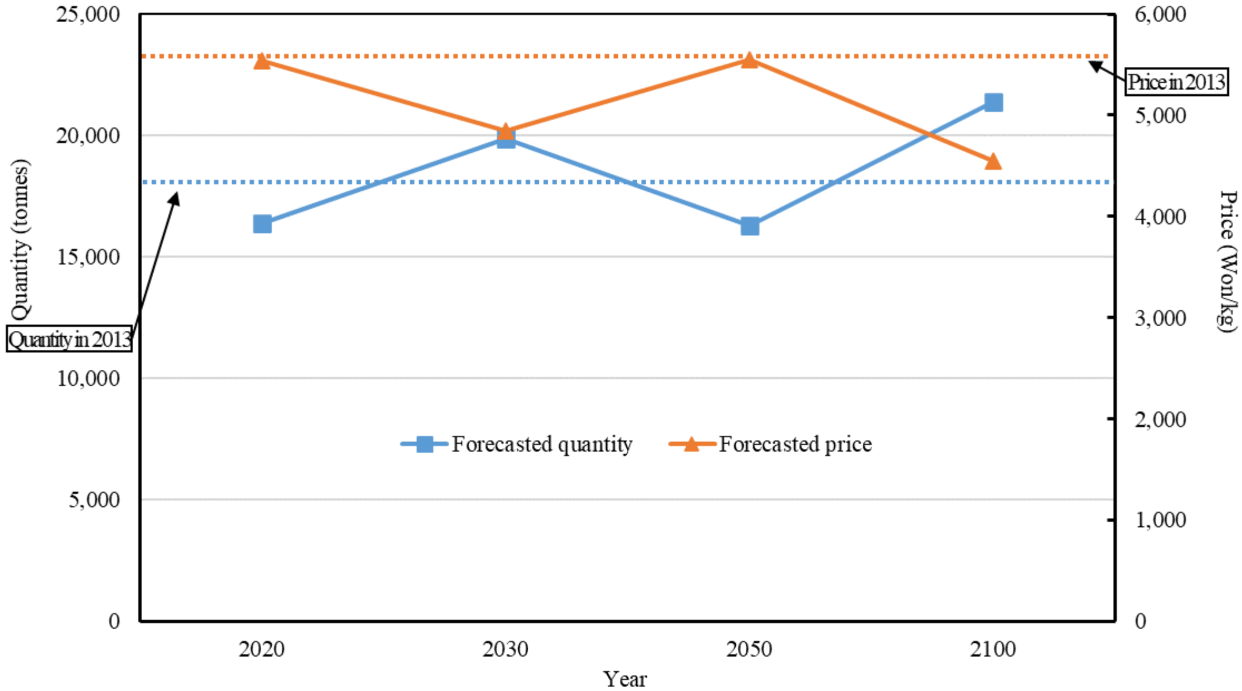

Figure A3. Projections of price and quantity of processed anchovy under RCP 4.5 for GN province

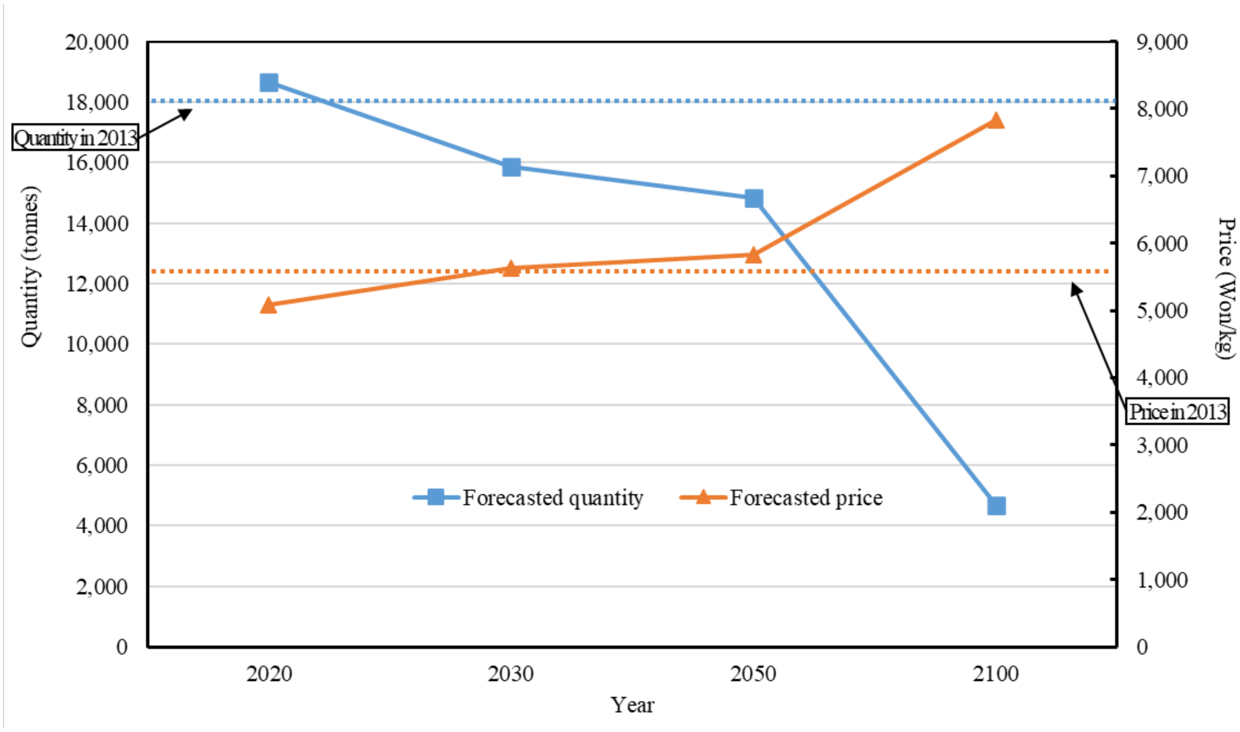

Figure A4. Projections of price and quantity of processed anchovy under RCP 8.5 for GN province

Figure A5. Projections of price and quantity of processed anchovy under RCP 4.5 for non-GN provinces

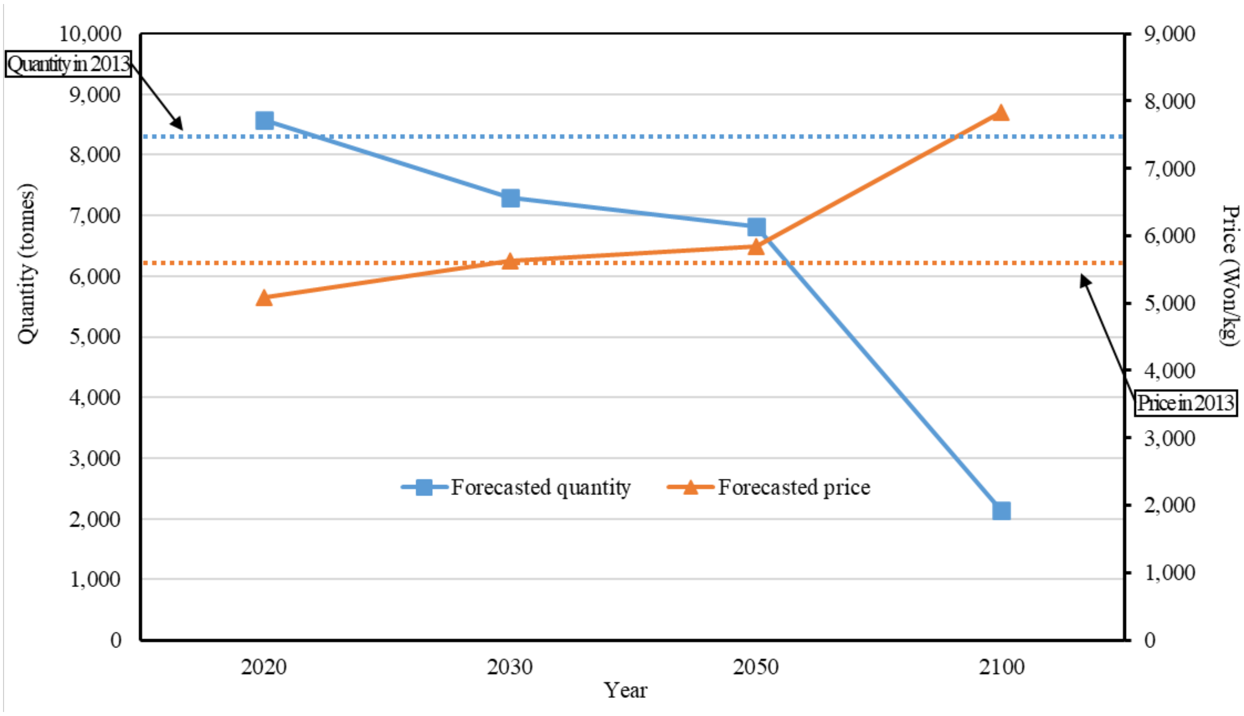

Figure A6. Projections of price and quantity of processed anchovy under RCP 8.5 for non-GN provinces