Title: MEY and MSY in a general equilibrium

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Data used for this study is available from the author upon reasonable request.

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Abstract

Most studies have focused on the effects of targeting Maximum Economic Yield (MEY) in fisheries using a partial equilibrium (PE) approach, which fails to assess the economy-wide effects and welfare impacts on society by overlooking the interactions between the fishing and non-fishing sectors. To address this limitation, this study develops a bioeconomic computable general equilibrium (CGE) model for a local fishery in Korea, embedded within a dynamic optimization framework, to calculate the economic and welfare effects of targeting MEY and Maximum Sustainable Yield (MSY). The CGE model considers varying degrees of the economy's openness regarding factor mobility and commodity trade while determining the input and output prices endogenously. Next, this study conducts various simulations to assess the model's sensitivity to different assumptions and bioeconomic parameters. This study reveals, among others, that in the steady state, the MEY is significantly lower in the GE model than in the PE model in most simulations, and that aiming for MEY often leads to a decrease in overall welfare in many simulations, while targeting the MSY typically enhances it. The study highlights the importance of employing a GE approach for accurately assessing the economy-wide effects of achieving the fishery management targets.

1. Introduction

Fishery managers around the world have traditionally focused on achieving a biologically sustainable level of fish populations (Bmsy), which maximizes the amount of fish that can be caught (MSY). However, Bmsy only takes into account biological sustainability and does not consider the economic benefits for fishermen. In response, some fishery managers have begun to adopt an alternative target: the biomass level (Bmey) that maximizes fishermen's profits (e.g., Australian fisheries, Department of Agriculture and Water Resources 2018, Kompas et al. 2010). Numerous studies have calculated the optimal harvest levels that achieve Bmey (e.g., Clark et al. 1979, Anderson 1986, Armstrong and Sumaila 2001, Grafton et al. 2010, Dichmont et al. 2010, Norman-Lopez and Pascoe 2011, Diop et al. 2018, Hoshino et al. 2018, and Natali et al. 2024).

However, the MEY model in all of these studies uses a partial equilibrium (PE) approach (Dichmont et al. 2010), which has several limitations. First, this approach implicitly assumes that changes in a fishery do not impact the broader economy, neglecting the effects that arise from interactions between the fishing sector and non-fishing sectors. Second, it pays little attention to inter-regional factor mobility (labor and capital) by implicitly assuming that factors of production are perfectly mobile between regions (countries or sub-national regions), so that factor prices do not change. Third, the PE approach does not adequately address inter-regional and international commodity flows that may result from changes in the fishery. It assumes that the trade of commodities, including fish, is perfectly elastic and that prices, including fish prices, remain constant (e.g., Armstrong and Sumaila 2001, Mardle and Pascoe 2002). While some studies (e.g., Sumaila et al. 2019, Pascoe et al. 2023) allow fish prices to vary in response to changes in fish landings, they still assume the prices of other commodities remain fixed. Other research (e.g., Punt et al., 2010; Kompas et al., 2010) considers changes in the price of important inputs, such as fuel, yet assumes that the prices of other intermediate inputs remain constant.

These assumptions are overly simplistic and do not accurately reflect reality. In the case of a sub-national region, there will be some inter-regional flow of factors, although they may not be perfectly mobile. Additionally, the inter-regional and international trade of commodities may not be perfectly elastic. Optimal levels of effort, harvest, and biomass are influenced by input and output prices, as well as biological parameters (Grafton et al., 2007). Since these prices (including those of non-fish commodities) change due to interactions between fishing and non-fishing sectors, assuming they remain constant in the PE model could lead to distorted estimates of MEY, affecting fishery managers' decisions.

A policy change that alters harvest levels will produce two types of effects: spillover effects and feedback effects. Spillover effects arise in non-fishing sectors due to initial policy changes in the fishing sector and include both backward and forward linkage effects. Backward linkage effects occur in non-fishing sectors (such as transportation services and insurance services), that supply inputs to the fishing sector. For instance, a reduction in fish harvesting will lead these non-fishing sectors to produce less output, which subsequently generates further multiplier effects as they reduce their purchases of inputs from other sectors. Forward linkage effects occur in sectors, such as fish processing and retail, that purchase raw fish from the fishing sector. If the fishing sector decreases its harvest, the output in these sectors will decline, leading them to purchase fewer inputs from all sectors. Consequently, market demand for these inputs will decrease, resulting in lower prices. Spillover effects also occur in factor markets. The factors of production released from the fishing sector due to reduced fish production will flow into non-fishing sectors (with some possibly exiting the region), increasing supplies in those sectors and leading to lower prices.

The feedback effects refer to the changes in the fishing sector that result from the changes in the market prices of inputs, which include both primary factors of production and intermediate inputs. Specifically, the prices set in the input markets influence the fishermen's decisions regarding optimal harvest levels. The PE approach assumes that the prices of most or all inputs in fishing remain fixed. When input price is allowed to vary (e.g., fuel price), it is estimated based on its forecast made outside of the PE model (e.g., Kompas et al. 2010), rather than being determined within it. This limitation means that the PE approach does not capture general equilibrium (GE) effects, including spillover and feedback effects. Consequently, it cannot assess the overall societal gains or losses in welfare arising from fishery management policies. In contrast, a GE model facilitates an evaluation of economy-wide effects and their impact on aggregate social welfare (Manning et al. 2018, Gilliland et al. 2022, Seung 2024, Seung et al. 2024a).

This study calculates the MEY for Busan's mackerel fishery in Korea, which is currently overexploited, using the GE approach. To achieve this, the study first develops a computable general equilibrium (CGE) model that is embedded within a dynamic optimization framework. The CGE model is a forward-looking, perfect foresight model (e.g., Babiker et al. 2009) where the fishermen make harvest decisions based on perfect expectations of future economic conditions.[1] As part of this study, a "PE version" of the CGE model is also developed, assuming the regional economy is completely open in terms of factor mobility and inter-regional and international trade.[2] Next, the study compares the results from the GE model with those from the PE model, highlighting the limitations of the PE approach.

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[1] To be more exact, the model used in this study is a partially forward-looking model in the sense that only the decisions made by mackerel harvesters are based on perfect expectations. In contrast, other economic agents, including non-mackerel-producing industries and households, base their decisions on myopic expectations, minimizing current-period production costs or maximizing current-period utility.

[2] In this paper, the term "PE version" is strictly reserved for the CGE model solved with a completely open economy while "PE approach", "PE model, "PE framework", or "PE analysis" refers to the partial equilibrium models in the previous studies solved without any other general equilibrium equations.

Furthermore, in the GE analysis of MEY, sensitivity analyses are conducted to explore (i) various assumptions regarding the openness of the economy in terms of inter-sectoral and inter-regional factor mobility as well as inter-regional and international trade, (ii) bioeconomic parameters, and (iii) the discount rate. As demonstrated, the optimal harvest levels can vary drastically depending on these assumptions and parameters. Lastly, this study reformulates the CGE model to calculate the MSY and compares these results with those from the GE-based MEY. Holma et al. (2019) compare the results from MEY and MSY, but within a PE framework, not accounting for the interactions between fishing and non-fishing sectors.

Fishery managers may be interested in the economy-wide effects of MSY and how these effects differ from those associated with targeting MEY. Furthermore, they face the question of whose benefits should be maximized or considered—those of fishermen or the overall benefits to society. While targeting MEY maximizes the rent for fishermen, this does not necessarily lead to the maximization of aggregate social welfare (Bromley 2009, Dichmont et al. 2010). As shown below, in most simulations, adopting MSY increases aggregate social welfare, whereas it tends to decrease under MEY.

There has been considerable debate in the literature regarding the relationship between MEY and MSY. Christensen (2009) claims that MEY equals MSY if benefits from fish harvesting to the processing and retail sectors are taken into account. However, in a subsequent discussion, Sumaila and Hannesson (2010) argue that MEY differs from MSY when society's resources are fully utilized, even considering the benefits to these sectors. Grafton et al. (2012) and Squires and Vestergaard (2016) further this discussion by considering the benefits to fish consumers, in addition to those received by the processing and retail sectors. While these discussions are important, they are not the primary focus of the present study. This study instead aims to quantify the GE effects on economic variables and the welfare implications of adopting MEY and MSY under varying economic (represented by factor mobility and trade elasticities) and ecological (represented by bioeconomic parameters) conditions, thus providing policy implications for fishery managers.

This paper makes several important contributions to the literature. First, it highlights the limitation of the PE approach when estimating the MEY by employing a GE approach. While there are numerous GE studies of fisheries (including CGE studies), none have explicitly addressed the limitation of the PE approach. This study begins to address this limitation. Second, this study considers factors that influence the effects of fishery management policies, which have not received much attention in existing literature, specifically, inter-regional factor mobility and trade. Previous GE studies (e.g., Brander and Taylor 1997, 1998) examined the role of international trade in the context of fishery management. However, these studies used a simplistic, theoretical two-sector model of a national economy, which did not account for inter-regional factor mobility and trade. Since most fisheries operate at a local level, it is crucial to consider these inter-regional flows of factors and commodities. The present study explicitly addresses this issue using a CGE model for a local fishery (Busan's mackerel fishery). Third, this study provides deeper insights into the ongoing policy debate surrounding MEY and MSY. Illustrating how backward and forward linkage effects occur demonstrates why this debate should be framed within a GE context.

This study demonstrates that the assumptions about the mobility of the factors of production influence their prices, while commodity prices are influenced by the degree of trade openness. Suppose fish harvests are reduced due to a policy. In that case, this reduction will lower the fishing sector's demand for factors of production, leading to an increase in the supply of these factors available to non-fishing industries as they are released from the fishing sector. This will drive down their prices. However, the extent of this price decrease hinges on the factor mobility assumptions; the more open regional factor markets are to the external economies, the smaller the price reduction. Similarly, a decline in harvest levels will lead to a larger supply of intermediate inputs for the non-fishing sectors, resulting in lower prices for these inputs. Again, the magnitude of this price drop will depend on trade openness; the more open the economies are to the external economies, the smaller the price decrease.

The various price outcomes resulting from differing assumptions or elasticities regarding openness will have different distributional consequences. Lower factor prices may lead to reduced incomes for factor owners (or value-added), which in turn negatively affects household income and welfare. Lower commodity prices can reduce production costs for industries. This, in turn, may boost factor income for industries and enhance purchasing power for households, thereby improving their welfare. The direction and magnitude of these distributional effects are determined by the assumptions about factor mobility and trade openness, as well as the interactions among sectors modeled in the CGE model. Given that the extent of openness varies across different fisheries, regions, and globally, it's crucial that the design of policies for local fisheries is grounded in a comprehensive understanding of the factor and trade markets that these fisheries face.

Chub mackerel (*Scomber japonicus*) (hereafter, 'mackerel') is found in warm or tropical waters, including offshore and coastal areas of Korea [National Institute of Fisheries Science (NIFS), 2021], and is a popular species along with anchovy and squid in Korean wild fisheries (Kim, 2017). In 2020, mackerel catch accounted for about 11% (77,401 tons) of the total catch from wild fisheries, generating an ex-vessel revenue of 163.6 billion Korean Won (KRW), or $138.6 million U.S. dollars[3]. This revenue ranks as the fourth largest among mackerel harvests, following hairtail, anchovy, and yellow croaker. In percentage terms, mackerel accounts for about 7% of the total ex-vessel revenue from wild fisheries [Korean Statistical Information Service (KOSIS), 2021].

[3] This figure is based on the average exchange rate in 2020 of 1,180 KRW for a US dollar. https://data.worldbank.org/indicator/PA.NUS.FCRF?end=2021&locations=KR&start=1995 Accessed Oct. 31, 2022.

The majority of mackerel catch (85.8%, or 66,444 tons) is captured using large purse seines, while the remainder is caught using set nets (3.4%, or 2,644 tons), small purse seines (2.7%, or 2,057 tons), offshore gillnets (2.2%, or 1,689 tons), and large pair trawls (2.1%, or 1,634 tons) (KOSIS, 2021). In 2021, the largest portion of the mackerel harvested in Korean waters was landed in Busan, accounting for 83% of the total catch from Korean waters. Mackerel production began at 38,256 tons in 1970 and grew steadily, reaching a peak of 415,003 tons in 1996. However, since then, it has been declining (KOSIS, 2021) due to reduced fish stock resulting from overexploitation. Hong and Kim (2021) report that the stock decreased from 1,263,316 tons in 1970 to 442,660 tons in 2020, which is well below its biological maximum sustainable yield (Bmsy) of 729,751 tons. They conclude that the stock is overfished.

To recover this stock, the Korean government has introduced various regulatory measures. In addition to implementing a Total Allowable Catch (TAC) system for the fishery in 1999, it prohibits mackerel harvesting for a month between April 1 and June 30 and sets a size limit of 21 cm for the fish [Korea Ministry of Government Legislation (MOLEG), 2021]. Thus, Busan's mackerel fishery is currently managed under regulated open access with TAC and license limitations in place. Despite the government's management efforts, the mackerel stock has been decreasing. In response, the government is considering adopting a rights-based management system, such as Individual Transferable Quotas (ITQ), to rebuild the stock. This may require a significant reduction in harvest, as shown in most of the simulations for MEY in the present study.

2. Methods

2.1 Review of previous fishery GE studies

Early examples of theoretical GE analyses include the works of Brander and Taylor (1997, 1998) and Congar and Hotte (2021). Brander and Taylor (1997) used a two-sector GE model for a small open economy operating under an open-access renewable resource regime. They demonstrated that if the economy has a comparative advantage in the resource good and remains diversified in production after engaging in trade, its steady-state utility decreases as a result of that trade. Brander and Taylor (1998) extended Brander and Taylor (1997) by allowing the world price of the resource good to be endogenously determined within a two-country GE model. Later, Congar and Hotte (2021) compared open access and restricted access regimes for a renewable resource within a two-sector GE model with mobile capital. They demonstrated that labor may benefit from the privatization of the resource by being discharged from the resource sector.

Numerous empirical CGE analyses of fisheries have also been conducted. For instance, Finnoff and Tschirhart (2008) linked a dynamic CGE model with an ecological GE model to study Alaska pollock fisheries. Waters and Seung (2010) assessed the economic impacts of reducing the total allowable catch (TAC) for Alaska pollock and an increase in fuel prices on the state's economy using a CGE model. Jin et al. (2012) developed a framework that combined a CGE model of a coastal economy with an ecological model to evaluate ecosystem-based fisheries management (EBFM) in New England. More recently, Wang et al. (2020) linked a CGE model with the Ecopath with Ecosim model to examine the socio-economic and ecosystem effects resulting from different scenarios of fishing effort and harvest management.

Meanwhile, Gilliland et al. (2022) explored the impacts of fishery rationalization on a rural fishing community in the Philippines using a CGE model. Apriesnig et al. (2022) combined a CGE model with Ecopath with Ecosim models to illustrate that neglecting the bidirectional feedbacks between a regional economy and the Lake Erie ecosystem can result in inaccurate biomass projections. Most recently, Seung et al. (2024a) examined the regional welfare effects of transitioning from a regulated open-access fishery to a rationalized fishery in a sub-national region of Korea, employing a forward-looking CGE model. Additionally, Seung et al. (2024b) used a recursive dynamic CGE model to identify stock rebuilding scenarios that maximize fishermen's rent, value-added, and social welfare, respectively. For reviews of other CGE studies for fisheries, see Akbari et al. (2023).

2.2 Busan CGE model

The CGE model used in the present study shares some similarities with the one in Seung et al. (2024a), but differs in important ways. First, while both models rely on dynamic optimization, the present study employs multi-level nested functions in the decision-making process of economic agents (households, firms, importers, and exporters) (See Figures B.3.1-B.3.4, Appendix B), whereas Seung et al. (2024a) did not. By allowing multiple stages in the economic agents' optimization, the present study provides flexibility in assigning values for the elasticity of substitution at various stages of optimization, and therefore, produces more accurate model results. Second, the present study explicitly demonstrates the limitation of the PE approach, while Seung et al. (2024a) did not. Third, the present study compares the implications of adopting MEY vs. MSY, while Seung et al. (2024a) did not.

This study is also distinguished from Seung et al. (2024b) in terms of the model dynamics. The CGE model in the present study is a forward-looking dynamic model, while the model in Seung et al. (2024b) is a recursive dynamic model. This means that the fish harvest in the present study is endogenously determined in each period, while it is given as an exogenous shock to the model in each period in Seung et al. (2024b). The reason these two studies employ different types of dynamic models is that the questions being asked in the studies are distinct. The present study asks, "What is the time path of the fish harvest when fishermen maximize the present discount value of their profit?" In contrast, Seung et al. (2024b) asks, "Which policy scenarios maximize the households' welfare, value-added, or fishermen's profits when the fishery managers exogenously reduce the TACs to rebuild the overexploited fish stock?"

This section provides an overview of the CGE model used in the present study. For more details, see Appendix B (Section B.1 for a list of model equations and Section B.2 for the data used and the calibration procedures employed.)

Production

The Busan CGE model has 36 industries (sectors) and 36 commodities, each of which is produced by the corresponding industry (Appendix A). These industries include two wild fish harvesting industries [mackerel harvesting industry (sector) and non-mackerel harvesting industry (sector)], one aquaculture industry, one fish processing industry, and 32 non-seafood industries.

In the base year (2015), Busan's total wild fish production was 262,037 tons, 50.3% of which was from the mackerel fishery, with the remainder from the non-mackerel fishery (KOSIS, 2022). The total ex-vessel value from the mackerel fishery was 201,638 million KRW (US $178.3 million[4], or 28.5% of total Busan's ex-vessel revenue from all fisheries of 706,558 million KRW) while the ex-vessel value from non-mackerel fishery was 504,920 million KRW (KOSIS 2022). Currently, Busan's mackerel fishery is managed under regulated open access with TAC and license limitations in place.

Production in each fish harvesting sector is determined through a three-stage optimization process (Figure B.3.1, Appendix B). In the first stage, harvest (*H*) is determined by a Cobb-Douglas (CD) aggregation of fishing effort (*E*) and fish biomass (*N*):

$$H = F(E,N) = \emptyset E^{f} N^{g}, \quad (1)$$

where *F*(*E,N*) is the harvest function, $\emptyset$ is the shift parameter (or catchability parameter), and *f* and *g* are, respectively, the effort and stock elasticities.

For the mackerel fishing sector, optimal effort levels are determined by maximizing the present discounted value of the present and future profits as:

$$\text{Max } OBJ = \sum_{t}^{T} \frac{1}{(1+d)^{t}} (PVI_t H_t - C_t E_t), \quad (2)$$

where *d* is the discount rate. When solving this problem, the following constraints are imposed:

(i) The initial level of biomass (N_{TF}) is set equal to its base-year level (N_0).
(ii) The harvest function above (Equation (1)).
(iii) The logistic growth function below (Equation (21)).

[4] In 2015, the average exchange rate for US dollar to Korean Won (KRW) was 1,131 KRW / US $. https://data.worldbank.org/indicator/PA.NUS.FCRF?end=2021&locations=KR&start=1995 accessed Oct. 31, 2022.

(iv) The condition that the growth of biomass equals the harvest in the last period (steady-state condition).
(v) All the other general equilibrium equations.

Solving this optimization problem with the constraints yields optimal levels of harvest (MEY) and effort.

When computing MSY, the objective function in Equation (2) is replaced by

$$\text{Max } OBJ = \sum_t^T H_t, \tag{3}$$

Maximizing this objective function with the constraints yields the optimal levels of harvest (MSY) and effort.

For the non-mackerel fishing sector, maximizing profit subject to the harvest function and the TAC level where the fishermen exhaust the full TAC, the effort demand function is derived as

$$E = \frac{k \cdot (PVI - \eta) \cdot H}{C}, \qquad \text{where } f < k < 1. \tag{4}$$

Here, the larger the *k,* the closer the fishery is to pure open access. Therefore, *k* can be called the degree of openness parameter (Seung et al. 2024a), and is calibrated using the base-year ex-vessel revenue and an estimated value of the resource rent (See Appendix B, Section B.2). *PVI* is the price (cost) of value-added plus intermediate inputs used to produce one unit of output, net of indirect business taxes (i.e., the price of one unit of output minus indirect business taxes); η is the marginal surplus of producing another unit of output; and *C* is the unit cost of effort with the effort being a combination of labor, capital, and intermediate inputs. Here, $(PVI - \eta)$ is the virtual price (Neary and Roberts, 1980) of the constrained output; that is, the price of output (net of indirect business taxes) that would induce the firm to choose *H* = *TAC*.

In the second stage, value-added composite (*LAK*) and the composite intermediate input (*INT*) are combined to produce effort (*E*) via a constant returns to scale (CRS), constant elasticity of substitution (CES) function:

$$E = \psi \left[\alpha (LAK)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)\,(INT)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{(\sigma-1)}}, \tag{5}$$

where ψ is the shift parameter, α and (1-α) are shares of *LAK* and *INT*, respectively, and σ is the elasticity of substitution. Cost minimization subject to the effort function yields demands for *LAK* and *INT*, respectively, as

$$LAK = \left(\frac{E}{\psi}\right)\left[\frac{\alpha\,\psi C}{PLK}\right]^{\sigma} \tag{6}$$

and

$$INT = \left(\frac{E}{\psi}\right)\left[\frac{(1-\alpha\,)\,\psi C}{PINT}\right]^{\sigma}. \tag{7}$$

Here, *PLK* and *PINT* are the prices of the two composite inputs, *LAK* and *INT*, respectively. The unit cost of effort (*C*) is given by

$$C = \frac{1}{\psi}\left[\alpha^{\sigma}(PLK)^{(1-\sigma)} + (1-\alpha)^{\sigma}(PINT)^{(1-\sigma)}\right]^{\frac{1}{(1-\sigma)}} \ . \tag{8}$$

In the third stage, firms combine labor (*L*) and capital (*K*) according to a CES value-added function to obtain the value-added composite (*LAK*) and combine individual intermediate inputs according to another CES function to form the composite intermediate input (*INT*). Similar to the second stage, the third stage yields demand functions for labor, capital, and individual intermediate inputs, along with the associated unit cost functions.

The production structure of the non-fishing industries is similar to that of the fish harvesting industries, except that there are no effort or biomass variables in their production. Firms in the non-fishing industries combine the composite value-added and the composite intermediate input using a CES function in the first stage. The optimization process in the second stage is the same as that for the third stage in the fish harvesting industry's production.

Household consumption

This study uses a multi-level nested CES utility function to represent the preference of the aggregate representative household, which allows flexibility in assigning values of the elasticity of substitution for different (groups of) commodities (including fish) (Figure B.3.2, Appendix B). To determine the quantities of the commodities consumed by the household, a four-stage optimization procedure is used. In the first stage, the demands for the composite food commodity (*FD*) and the composite non-food commodity (*NFD*) are determined by maximizing the utility:

$$U = \left[\beta^{\mu}FD^{(1-\mu)} + (1-\beta)^{\mu}NFD^{(1-\mu)}\right]^{\frac{1}{(1-\mu)}} \ , \tag{9}$$

subject to its budget constraint:

$$DYH = P_{FD}FD \ + \ P_{NFD}NFD \ . \tag{10}$$

Here β and μ are share parameter and elasticity of substitution, respectively; *DYH* is disposable income; and P_{FD} and P_{NFD} are the prices of the composite goods *FD* and *NFD,* respectively.

Demand functions for *FD* and *NFD* are derived from the first-order conditions:

$$FD \quad = \frac{\beta\, DYH}{P_{FD}{}^{\mu}\left[\beta P_{FD}{}^{(1-\mu)} + \ (1-\beta)\, P_{NFD}{}^{(1-\mu)}\right]} \tag{11}$$

and

$$NFD = \frac{(1-\beta)\, DYH}{P_{NFD}{}^{\mu}\left[\beta P_{FD}{}^{(1-\mu)} + \ (1-\beta)\, P_{NFD}{}^{(1-\mu)}\right]} \ . \tag{12}$$

The unit expenditure (*UE*) function is given as

$$UE = \left[\beta P_{FD}{}^{(1-\mu)} + \ (1-\beta)\, P_{NFD}{}^{(1-\mu)}\right]^{\frac{1}{1-\mu}} \qquad . \tag{13}$$

In the second stage, given the quantity of *FD* in the first stage, the demand functions for the composite seafood commodity and the composite non-seafood food commodity are derived by minimizing the cost of consuming these two composite goods subject to a CES *FD* aggregation function. The unit expenditure function for *FD* is given in a form similar to Equation (13) above. Similarly, in this stage, the demands for the individual non-food commodities (*NF1, NF2, …, NFn*) are determined by minimizing the cost of these commodities subject to a CES *NFD* aggregation function, and the unit expenditure function for *NFD* is derived.

This study follows a similar procedure to derive the demands for the composite raw fish commodity and processed seafood in the third stage and the unit expenditure function for the composite seafood commodity. Finally, in the fourth stage, the demands for the individual raw fish commodities (i.e., mackerel, non-mackerel, and farm-raised fish) are derived along with the unit expenditure function for the composite raw fish commodity.

This study uses equivalent variation (*EV*) to measure the welfare change for the household, and is given by

$$EV = e(\boldsymbol{p}^0, U^1) - \ e(\boldsymbol{p}^0, U^0) \ \ , \tag{14}$$

where *e* denotes expenditure function, $\boldsymbol{p}^0$ is a vector of pre-policy prices of the two composite commodities in the top nest in the utility tree (*FD* and *NFD*, Figure B.3.2, Appendix B), and U^1 and U^0 are post- and pre-policy levels of household utility, respectively.

Imports

Users of a commodity (households, industries, and the government) in Busan consume a combination of three different versions of the commodity, sourced from three different locations – the study region, the rest of the country (ROC), and foreign countries. It is assumed that the three different versions are qualitatively different and imperfect substitutes for one another and that their prices can be different (Armington 1969). Users undertake a three-stage optimization process to determine their consumption of the commodity (Figure B.3.3, Appendix B). In the first stage, the region's total demand for each commodity is determined by adding up the demands from households, industries (intermediate demand, investment demand), and governments.

Once the total demand is determined in the first stage, the second stage computes the quantities of the commodity sourced from the country and its imported counterpart from foreign countries by minimizing their expenditure on the two different versions of the commodity, subject to a CES Armington function (Armington 1969):

$$Q = A[\delta M^{-\rho} + (1-\delta)\, D^{-\rho}\,]^{-\frac{1}{\rho}} \text{ where } \rho = -1 + \frac{1}{\epsilon}. \qquad (15)$$

Here, Q is the composite commodity consisting of foreign-sourced (M) and domestically produced (D) versions; A, δ, ρ, and ϵ are the shift parameter, share parameter, exponent, and elasticity of substitution, respectively. This yields import demand function for the foreign-sourced commodity (M), which is downward sloping:

$$M = \left(\frac{PD}{PM}\right)^{\epsilon} \left(\frac{\delta}{1-\delta}\right)^{\epsilon} D\,, \qquad (16)$$

where PD and PM are, respectively, the price of the domestically produced commodity and the price of its imported counterpart from foreign countries.

Given the composite commodity sourced from domestic regions in the second stage (D), the third stage determines the quantities of regionally-produced commodity and the version sourced from ROC by minimizing the total expenditure on the two different versions of the commodity, subject to another CES Armington function. This yields the import demand function for the commodity from ROC, which has a form similar to Equation (16) above. This demand function is also downward sloping.

For foreign imports, this study adopts the "small country (region)" assumption that the region's imports of goods (including fish) from foreign countries do not exert a strong influence in the foreign markets. This means that the region faces an infinitely elastic import supply function for foreign-sourced goods and that the prices of imports from foreign countries are fixed at their base-year levels. On the other hand, since Busan is one of the major economic regions within Korea, greatly influencing the pricing of the commodities in domestic markets through domestic imports, the region is assumed to face an upward-sloping import supply curve (i.e., less-than-infinite elasticity) for the goods imported from the ROC:

$$M_{DOM} = \varphi \cdot \overline{M_{DOM}} \cdot (PM_{DOM})^{\gamma} \quad , \tag{17}$$

where M_{DOM} is imports from ROC, $\overline{M_{DOM}}$ is its base-year level, φ is the shift parameter, PM_{DOM} is the price of M_{DOM}, and γ is the elasticity of import supply.

Exports

Firms in Busan undertake a three-stage optimization to distribute their output (Figure B.3.4, Appendix B). In the first stage, they determine their output level by maximizing profit (or minimizing cost). Once the total output of a commodity is determined in the first stage, they determine in the second stage the quantities of the commodity supplied to two different destinations – domestic regions (including the study region) and foreign countries, by maximizing their revenues from sales of the commodity to the two different markets subject to a constant elasticity of transformation (CET) function:

$$Z = T[\omega EX^{\pi} + (1-\omega)\, G^{\pi}\,]^{\frac{1}{\pi}} \text{ where } \pi = 1 + \frac{1}{\varepsilon}. \tag{18}$$

Here, Z is the composite commodity consisting of the commodity exported to foreign countries (EX) and its domestically supplied counterpart (G); T, ω, π, and ε are the shift parameter, share parameter, exponent, and elasticity of substitution, respectively.

This yields an export supply function for the commodity exported from the region to the foreign market, which is upward-sloping:

$$EX = \left(\frac{PE}{PG}\right)^{\varepsilon} \left(\frac{1-\omega}{\omega}\right)^{\varepsilon} G \ , \tag{19}$$

where PE and PG are, respectively, the price of the commodity exported to foreign countries and the price of the domestically supplied version.

In the third stage, given the quantity of the composite commodity supplied to domestic regions (G) from the second stage, the firms maximize their revenue from sales of the commodity to two different domestic regions (the study region and ROC), subject to another CET function. This yields an export supply function for the commodity exported to ROC, whose form is similar to Equation (19) above.

Again, this study adopts the “small country (region)” assumption that the region’s exports of goods (including fish) to foreign countries do not substantially influence the pricing of the goods in foreign markets. This means that the region faces an infinitely elastic export demand (i.e., foreign countries' demand) for the goods from the region and that the price of exports to foreign countries is fixed at its base-year level. As in domestic imports above, it is assumed that the region exercises strong power in ROC's market via its exports and that the region faces the export demand (i.e., ROC's demand) for the goods produced in the region that is less than infinitely elastic:

$$E_{DOM} = \theta \cdot \overline{E_{DOM}} \cdot \left(\frac{1}{PE_{DOM}}\right)^{\tau}, \tag{20}$$

where E_{DOM} is domestic exports, $\overline{E_{DOM}}$ is its base-year level, θ is the shift parameter, PE_{DOM} is the price of the domestically exported good, and τ is the elasticity of export demand.

Regional factor mobility

Several CGE studies of fisheries (e.g., Apriesnig et al. 2022; Manning et al. 2018) assume that the total stocks of labor and capital (vessels) available in the study region are fixed. This means that if the fishing industry frees up some of the factors of production due to a policy change (e.g., a lower TAC), they can flow to non-fishing industries within the region. In contrast, Gilliland et al. (2022) assume that capital is fixed in the rationalized sector both before and after the fishery reform, as well as in each of the non-fishing industries. The factor mobility assumptions used in these studies may be appropriate for their respective study regions. Furthermore, there is no strong empirical evidence regarding the inter-sectoral and inter-regional mobility of factors used in fisheries.

This study considers three different possibilities of factor mobility. First, both labor and capital are perfectly mobile across sectors and regions, which means that their prices remain fixed at their base-year levels. Second, both factors are only mobile within the region, implying that the factor markets are closed to outside economies. In this case, a single price for each factor is determined endogenously within the CGE model. Third, only one of the factors is perfectly mobile between sectors and regions. In this case, the price of this factor is fixed at its base-year level, while the price of the other factor is determined endogenously within the CGE model.

Fish stock growth

When the harvest level (*HARV*)[5] changes due to adopting MEY or MSY, it changes the stock level (*N*). In this study, the stock is assumed to grow following the logistic growth function:

[5] The harvest level earlier in this paper was denoted *H,* which measures the fish production calibrated with its base-year price set to one. *HARV* measures the fish production in its actual weight (tons).

$$N_{t+1} = N_t + \gamma N_t \left(1 - \frac{N_t}{KC}\right) - HARV_t \ , \quad (21)$$

where N_t is the stock level in period t, γ is the intrinsic growth rate, KC is the carrying capacity, and $HARV_t$ is the harvest level (in tons) in period t. Thus, the increase in the stock level will raise the marginal productivity of effort, as indicated by Equation (1).

RESULTS

Descriptions of simulations

This study conducts a total of 33 simulations and sensitivity analyses (Table A.3. Appendix A). The first simulation, named SQ, replicates the status quo of regulated open access for the mackerel sector, solving the CGE model for the baseline levels of all endogenous variables (e.g., harvest levels) that remain constant over time. In this simulation, baseline parameter values and assumptions (Tables B.2.1 and B.2.2, Appendix B) are used. To solve for SQ, the discount rate is set to infinity (Clark 1990).[6]

The remaining 32 simulations are divided into two groups: the first group consists of 16 simulations (MEY1-MEY16) that calculate MEY, while the second group contains the other 16 simulations (MSY1-MSY16) that compute MSY. In all simulations, a sufficient number of solution periods is allowed, with the last period extending to the 100th year beyond the base year. It is found that by the 30th year, all economic and ecological variables are sufficiently close to the steady state. The economic effects are determined by comparing the results from each of the 32 simulations with SQ. The first simulation in each group (MEY1, MSY1) solves the CGE model using the baseline parameters and assumptions (Tables B.2.1 and B.2.2, Appendix B) closest to the Busan's mackerel fishery for MEY or MSY. In these two simulations, both labor and capital are perfectly mobile within the study region and across regions, and the trade elasticities for all commodities are set at baseline values. These two simulations are referred to as the baseline simulations for MEY and MSY, respectively. Appendix B (Section B.2) provides further descriptions of the domestic and foreign trade-related functions, as well as the values of the elasticities used in the baseline simulation.

The remaining simulations in each group are conducted to perform sensitivity analyses on three different types of assumptions or parameters. The first type involves assumptions regarding the openness of the economy (MEY2-MEY6, MSY2-MSY6). The second type includes bioeconomic parameters such as stock elasticity (MEY7 and MEY8, MSY7 and MSY8), the initial ratio of biomass to carrying capacity (MEY9 and MEY10, MSY9 and MSY10), and intrinsic growth rate (MEY11 and MEY12, MSY11 and MSY12). The

[6] There are two different ways of solving the status quo (regulated open access). It can be solved either using a recursive dynamic model (e.g., Congar and Hotte 2021) without Equation (2) or using a forward-looking dynamic model (Clark 1990) with the discount rate set to infinity in Equation (2). This study adopted the latter approach (Clark 1990).

third type encompasses two additional parameters: the Armington elasticity for mackerel (MEY13 and MEY14, MSY13 and MSY14) and the discount rate (MEY15 and MEY16, MSY15 and MSY16). For the sensitivity analyses related to the last two types of parameters, this study maintains the openness assumption as stated in MEY1 (or MSY1).

As the simulations progress from MEY2 to MEY6, the economy becomes more open. MEY2 represents a highly closed economy, calculating MEY with closed factor markets and highly inelastic trade. MEY3 assumes closed factor markets but moderate trade elasticity. In MEY4 and MEY5, trade is moderately elastic, with only one factor being inter-regionally mobile (labor in MEY4 and capital in MEY5), while the total stock of the other factor remains fixed.

In contrast, MEY6 calculates MEY with a perfectly open economy. The results for effort, harvest, and stock from this simulation are nearly identical to those obtained from the PE model, with infinitesimal changes in prices. This means that the PE model is a special case of the GE model with a perfectly open economy. MEY6 will henceforth be referred to as the "PE version" of the GE model. MEY7-MEY12 conduct sensitivity analyses on bioeconomic parameters, while MEY13-MEY16 investigate the model sensitivity to Armington elasticity for fish (MEY13 and MEY14) and discount rate (MEY15 and MEY16). MSY1-MSY16 are for MSY, and are similar to those for MEY except that they are solved for MSY. More details are found in Table A.3 (Appendix A) and Table B.2.3 (Section B.2, Appendix B.

The results from the majority of simulations are presented in Tables 1-4, Figure 1, and Figure C.1 (Appendix C), illustrating changes relative to the status quo (SQ). Variations in (i) intrinsic growth rate, (ii) the Armington elasticity of mackerel imports from foreign countries (as detailed in the first stage of the Armington function below), and (iii) the discount rate do not produce significantly different outcomes for both MEY and MSY. Therefore, the results from these sensitivity analyses are provided in Appendix C (Tables C.1 and C.2).

Results from MEY simulations

This study first compares the effects of targeting the MEY calculated from the GE model, which is solved with baseline assumptions and parameters (referred to as Baseline simulation or MEY1), against those from the PE model. In the first two years, both models show a harvest reduction of over 60% (see Figure 1, top left, labeled MEY GE and MEY PE), with slightly larger reductions observed in the PE model. From the third year onward, the GE model exhibits larger decreases in both harvest and effort compared to the PE model (Figure 1, top left and top right). This results in a fish price increase of over 10% in the initial years (Figure 1, bottom left) and a lower effort price (not shown), whereas prices remain fixed in the PE model (Figure 1, bottom left). As time passes, however, the higher fish price induces an increase in fish imports and a decline in fish exports, resulting in a greater fish supply in the region compared to the status quo (SQ).

This dynamic does not occur in the PE model. Additionally, the lower effort price in the GE model triggers an out-migration of labor and capital from the region (Figure C.1, Appendix C).

The increased supply of fish exerts downward pressure on the fish price (Figure 1, bottom left), causing the harvest in the GE model to decline more than in the PE model (Figure 1, top left). The disparity in results between the two models arises because, in the GE model, fishermen take into account changes in both present and future fish prices and input costs, as well as changes in biomass, when determining harvest levels. In contrast, in the PE model, fishermen only consider the changes in biomass given the fixed prices.

In steady state, the GE model shows a larger biomass increase than the PE model (Table 1, Column 2, with PE results in parentheses). This is because the harvest in the GE model begins to diminish more significantly beyond the third year (Figure 1). In steady state, the harvest is 13.4% lower in the GE model, while it is only 5.1% lower in the PE model (Table 1, Column 2), relative to SQ. In MEY1, a decrease in demand for factors of production in the fishery lowers their market prices (not shown). Consequently, some of the factors of production exit the region without being absorbed into non-fishing sectors (Figure C.1, Appendix C). Additionally, the reduced harvest leads to a smaller demand for intermediate inputs from non-fishing sectors, resulting in a decrease in these sectors' output (-0.014%) and value-added (-225.7 billion KRW, Table 1, Column 2). The significant rent increase (358.0 million KRW, Table 1) is insufficient to offset the loss in value-added from non-fishing sectors, resulting in a net aggregate welfare loss of 358.6 billion KRW (Bromley 2009).

In the baseline simulation for MEY (MEY1), both total labor (Figure C.1, left) and total capital (Figure C.1, right) in the non-mackerel sector decrease in the long run. Furthermore, total regional labor (Figure C.1, left) and total regional capital (Figure C.1, right) decrease, meaning that both factors of production leak out of the region due to the implementation of MEY.

Given the discount rate, the optimal path for the GE-based MEY model (MEY1, Figure 1) is determined by the current and future levels of fish biomass, as well as the market prices of fish and inputs. Fishermen take these variables into account and smooth out their harvest over time to maximize the present discounted value of their profits. When the current harvest exceeds the optimal level, future fish biomass will decline, leading to a lower supply in subsequent periods. Knowing that future fish prices are expected to be higher while future input prices will likely be lower, fishermen will reduce their current harvest to take advantage of the anticipated higher future fish prices and lower input costs. Conversely, if the current harvest is below the optimal level, future fish biomass will be larger, resulting in lower future fish prices and higher input prices. In this situation, fishermen will increase their current harvest to capitalize on the potential for larger profits. In contrast, within the PE-based MEY model, fishermen determine the current level of harvest based solely on expected future biomass levels, given the discount rate, assuming that fish and input prices remain constant. In both models, fishermen continually adjust their harvest over time until a steady-state equilibrium is achieved, at which point both harvest and biomass levels stabilize.

In MEY2, which represents a highly closed economy, the prices of the intermediate inputs (commodities) used in fishing rise more than in any other simulation presented in Table 1. These higher input prices result in a significant decline in harvests of up to 21.6%. Coupled with the highly inelastic trade of fish, this leads to a sharp rise in the fish price of 6.4%. The drastic reduction in harvest explains the greatest increase in biomass, at 152.1%, compared to the other simulations in Table 1. Additionally, the combination of a sharp increase in fish price and a substantial decrease in effort (64.0%) contributes to a remarkable increase in rent (376.3 million KRW). With closed factor markets, all factors of production from the fishing sector are redirected to the non-fishing sectors, resulting in an increase in their output (0.110%) and value-added (696.6 billion KRW), despite the reduced demand by the fishing sector for the intermediate inputs from the non-fishing sectors. This, combined with the significant rent increase, enhances overall welfare by 108.7 billion KRW.

In MEY2, trade is highly inelastic, whereas it is moderately elastic in MEY3. This difference leads to a smaller increase in aggregate welfare in MEY2 compared to MEY3. The higher prices of all commodities in MEY2—due to the highly inelastic trade—result in a greater reduction in purchasing power for residents than in MEY3.

In MEY4, capital released from the fishing sector flows into the non-fishing sectors, contributing to a substantial increase in output (0.184%) and value-added (1,753.3 billion KRW) in the non-fishing sectors. This results in the largest gain in aggregate welfare, amounting to 805.8 billion KRW. Consequently, some labor migrates from outside the region to the non-fishing sectors (not shown) to support the increased output. However, when capital is allowed to move between regions with the total labor stock fixed (MEY5), total value-added in the non-fishing sectors declines by 32.0 billion KRW, despite a slight increase in output (0.003%). This leads to a decrease in aggregate welfare (-272.3 billion KRW). The results of MEY5 indicate that permitting capital outmigration from the region has negative consequences for aggregate welfare. MEY6 (PE version, Table 1, last column) shows the same results for biomass, harvest, and effort as the PE model (parentheses in Column 2).

In MEY1, a stock elasticity of 0.4 is used (see Appendix B, Section B.2). A sensitivity analysis (Table 2) then adjusts this elasticity value, increasing it to 0.60 (MEY8) and lowering it to 0.20 (MEY7). In the steady state, the high stock elasticity results in a smaller decrease in harvest (2.4%) and a smaller increase in stock (124.9%) compared to the low elasticity simulation. This occurs because a higher elasticity with a given stock level implies higher fishing productivity, resulting in a less pronounced decline in harvest (2.4%). Consequently, the stock size does not increase as much as in the low elasticity case (MEY7). Moreover, a higher stock elasticity involves a greater reduction in fishing effort (72.0%). Rent increases more in MEY8 (577.0% vs. 168.9%) due to the smaller harvest decline and larger effort reduction. Despite this significant rent increase, aggregate welfare in MEY8 does not increase.

In the base year, the initial biomass-to-carrying capacity ratio is 0.312. To assess model sensitivity, this value is adjusted by 50%, resulting in a high ratio of 0.468 (MEY10) and a low ratio of 0.156 (MEY9). If the initial stock is more abundant (MEY10), rent increases by less (259.9%) than in the baseline simulation (MEY1) because there is less room for improvement; that is, the gap between the initial stock level and Bmey becomes smaller. Under these conditions, biomass grows by only 69.1% in MEY10, despite a significant harvest reduction of 33.5%, which contrasts with results from MEY1. Conversely, if the initial stock is considerably degraded (MEY9), rent increases more significantly (639.0%), leading to a larger harvest (51.2%) in the steady state and an increase in aggregate welfare. This study also conducts sensitivity analyses for the bioeconomic parameters within the PE model for MEY, and results are available upon request.

Results from MSY simulations

Achieving MSY in the baseline simulation (MSY1) requires a two-year closure of the fishery to allow the stock to recover (Figure 1, top left, trajectory labeled MSY GE). After this closure, the stock rapidly increases by 60.4% compared to the status quo (Figure 1, bottom right, and Table 3). The biomass-to-carrying-capacity ratio rises to 0.5 in the third year, up from its base-year value of 0.312, and remains stable afterward. This simulation results in a steady-state harvest level that is 16.5% higher than the status quo. During the closure, fish price significantly rises, but it quickly stabilizes afterward at a level that is 2.0% lower than the status quo (see Figure 1, bottom left, and Table 3).

In the baseline simulation for MSY (MSY1), aggregate welfare increases by 98.9 billion KRW in the steady state (Table 3). In contrast, the baseline simulation for MEY (MEY1) predicts a decrease in aggregate welfare by 385.6 billion KRW (Table 1, Column 2). This difference primarily arises because the MSY model (MSY1) allows for a larger harvest (16.5%), which leads to greater output in both backward-linked sectors (e.g., fuel, repair) and forward-linked sectors (e.g., fish processing, retail trade, Christensen 2009) compared to the MEY model (MEY1). However, the increase in the non-fishing sectors' output (0.006%) in this simulation does not result in a corresponding increase in value-added, which decreases by 1.3% due to lower factor prices (not shown). Nevertheless, the increase in rent more than compensates for the loss in value-added in the non-fishing sectors, ultimately resulting in a net increase in aggregate welfare in MSY1.

In the baseline simulation for MSY (MSY1), both total labor (Figure C.1, left) and total capital (Figure C.1, right) in the non-mackerel sector increase in the long run due to an increased mackerel harvest under MSY. As a result, total regional labor (Figure C.1, left) increases, although total regional capital (Figure C.1, right) decreases only slightly. These results are contrasted with those obtained under MEY as shown in Figure C.1.

With a highly closed region (MSY2), the prices of all commodities (except the fish price) rise more significantly than in MSY1 due to highly inelastic trade (not shown). This situation leads to higher costs for the intermediate inputs used in fishing and exerts greater downward pressure on the harvest level. However, because this simply means that the fish supply exceeds the desired amount given the fixed level of harvest (MSY), the fish price falls lower (3.4%), and the rent will increase by less (165.1%) than in MSY1. The increase in output and value-added in the non-fishing sectors in MSY2 can be attributed to two factors. First, a large harvest creates a significant demand for outputs from the non-fishing sectors. Second, all factors of production from the fishing sector flow to the non-fishing sectors, boosting their output and value-added. Combined with the rent increase, this results in an overall improvement in aggregate welfare.

The key difference between MSY2 and MSY3 lies in the elasticity of trade. In MSY3, trade is moderately elastic, which significantly impacts the welfare results. The substantial increase in commodity prices resulting from the highly inelastic trade in MSY2 reduces the purchasing power of residents more than in MSY3. This, along with a smaller rent, leads to a smaller increase in aggregate welfare (115.6 billion KRW) in MSY2. In MEY4, adopting MEY with the assumption of a fixed total capital stock results in the largest increase in aggregate welfare (805.8 billion KRW) among all the alternative factor market assumptions presented in Table 1. Similarly, in MSY4, achieving MSY under the same assumption leads to the largest increase in aggregate welfare (387.4 billion KRW) among all factor market assumptions shown in Table 3. Additionally, MSY6 (PE version) demonstrates that the prices of all commodities, including fish, change only slightly (last column of Table 3). A key advantage of employing a GE model for estimating MSY is its ability to quantify the impacts on variables such as the output of non-fishing sectors and aggregate welfare, which a PE model cannot assess.

Results from sensitivity analyses indicate that the larger the stock elasticity, the larger the reduction in effort (27.9%) with the increase in harvest fixed (16.5%), and the larger the increase in rent and welfare gain (MSY1 vs. MSY8, Table 4). Additionally, the higher the initial ratio of biomass to the carrying capacity, the smaller the increase in the harvest (0.4%) (MSY1 vs. MSY10). The aggregate welfare can even diminish (-3.6 billion KRW) with the high ratio. This study also conducts sensitivity analyses for the bioeconomic parameters within the PE model for MSY. Results are available upon request.

DISCUSSION

Numerous studies have explored the effects of targeting MEY (e.g., Armstrong and Sumaila, 2001; Grafton et al., 2010; Dichmont et al., 2010; Costello et al., 2016). However, all these studies use a PE approach, ignoring the interactions between fishing and non-fishing sectors. This study uses Busan's mackerel fishery as a case example to address this issue, demonstrating that reliance on the PE model can lead to distorted fishery management decisions by suggesting an excessively high TAC. While some studies (Norman-Lopez and Pascoe, 2011; Sumaila et al., 2019, and Brito et al., 2024) attempt to link fishing with non-fishing sectors using an input-output model (multipliers), they ignore the feedback effects.

This study shows that PE-based and GE-based results for MEY are significantly different (Table 1, Column 2). The magnitude of the difference depends on the assumptions about the openness and the bioeconomic and other parameters. For example, when the economy is highly closed (MEY2, Table 1, Column 3), the difference in results for harvest from PE and GE approaches is very large (-5.1% vs. -21.6%). This means that fish managers should consider the economic conditions of the study region (represented by openness and bioeconomic parameters) when determining harvest levels.

In this research, the net effects of MEY and MSY on non-fishing sectors are determined by the relative strengths of two opposing spillover effects: (i) spillover effects linked to intermediate inputs, and (ii) spillover effects related to primary production factors. The first type of effect occurs when changes in the fishing sector lead to corresponding changes in the output of non-fishing sectors via backward and forward linkages. The second type occurs when changes in the fishing sector cause production factors to move from (to) the fishing sector to (from) the non-fishing sectors or outside the region. The first type of effect is generally negative for MEY in most simulations, while it is typically positive for MSY. The impact of the second type depends on assumptions regarding factor mobility.

Previous PE models addressing MEY fail to account for issues related to factor mobility for two main reasons. First, these models are inherently PE models where inter-sectoral or interregional factor mobility is not factored in. Second, the geographical boundary of the study region is often vaguely defined. It is unclear whether the studies pertain to an entire country or a specific sub-national region. If the focus is on a country, one must consider factor mobility between the fishing and non-fishing sectors. If the focus is on a sub-national region, one must consider factor mobility between that region and the rest of the country, as well as between the fishing and non-fishing sectors within the region.

The present study is capable of investigating both inter-sectoral and inter-regional mobility of factors, as factor markets are included in the CGE model. In the simulations where the total regional labor stock is fixed (MEY2, MEY3, MEY5, MSY2, MSY3, and MSY5), a single wage rate is endogenously determined within the model. In these simulations, labor that is released from the fishing sector can find employment opportunities in other sectors of the economy. Conversely, in simulations where labor is mobile, both between sectors within the region and between the study region and the rest of the country (in all other simulations), the wage rate is fixed and equalized across both sectors and regions. Therefore, in such cases, released labor can exit the region if no employment opportunities are available within it.

Similar assumptions apply to capital. When capital is released from the fishing sector, it is assumed to either be absorbed by the region's non-fishing sectors or exit the region entirely. If the capital is sufficiently malleable—meaning it can be quickly transformed for use in other fishing or non-fishing sectors—then the released capital may flow into other sectors within the region, resulting in an endogenous determination of a single rate of return on capital (MEY2-4, MSY2-4). However, in reality, fishing capital is usually not malleable, especially in the short term. Therefore, it is unlikely that capital from the fishing sector will be utilized in non-fishing sectors. Additionally, it is improbable that fishing capital from one fishing sector will transfer to another, as those sectors often face license limitations that restrict additional fishing capacity. Moreover, harvest levels in these other fishing sectors are fixed according to TACs, which limits the influx of released fishing capital. Thus, if the capital is non-malleable, it plays no role in either the other fishing or non-fishing sectors and will likely exit the regional economy. Results from other simulations (i.e., all simulations except MEY2-4, MSY2-4), where capital can exit the region, illustrate this situation.

This study finds that aggregate social welfare increases under MEY when the regional economy is moderately or highly closed (MEY2-4), where total regional capital is fixed and malleable, or when the initial ratio of biomass to carrying capacity is low (MEY9). This observation aligns with Norman-Lopez and Pascoe (2011), who argue that implementing MEY can generate overall long-term benefits for the entire economy. However, for many regional economies, including Busan's, the assumption of moderate openness (MEY1 and MEY7-16) appears more plausible than alternative assumptions (MEY2-6). In most simulations, except for four (MEY2-4 and MEY9), targeting MEY has a negative impact on the economic well-being of the entire society (regional residents), consistent with findings from Bromley (2009) and Wang and Wang (2012).

MEY3 assumes that the factor markets are closed while commodity trade is moderately open. The results from this simulation are expected to be qualitatively similar to those that <u>would</u> be obtained from a national GE model for MEY, as the model often operates under this assumption.[7]

The advantages of using a GE approach become more apparent when comparing the results from MEY2 (a highly closed economy) with those from MEY6 (PE version, a completely open economy). For instance, while the PE version predicts a harvest reduction of 5.1%, MEY2 predicts a significantly larger reduction of 21.6%. Sensitivity

[7] Although there are some theoretical national-level GE studies for fisheries (e.g., Brander and Taylor, 1997; Brander and Taylor), these studies did not specifically examine MEY. However, there are a large number of national-level non-fishery CGE models in the literature (e.g., Löfgren et al., 2002).

analyses of the bioeconomic parameters underscore the importance of accurately estimating the fish stock and its associated parameters. Although variations in the intrinsic growth rate do not significantly affect the steady-state results, changes in the other two parameters—stock elasticity and the initial ratio of biomass to carrying capacity—greatly impact the results.

Several studies have sought to redefine MEY to encompass the benefits that extend beyond the fishing sector, specifically, those benefits derived from forward-linked sectors such as processing and retail (Christensen, 2009), as well as from consumers (Sumaila and Hannesson, 2010; Grafton et al., 2012; Squires and Vestergaard, 2016). These studies argue that to maximize benefits for these stakeholders, fish production should increase, moving toward MSY. However, these studies typically include only some parts of the economy when calculating the benefits from the redefined MEY. In contrast, this study employs a GE approach that accounts for all sectors linked to fishing, including both forward-linked and backward-linked sectors, when assessing changes in aggregate welfare.

Additionally, this study determines MSY using a CGE model that includes all relevant sectors, evaluates the spillover effects of the fishing sector on non-fishing sectors, and compares the results with those derived from MEY. Holma et al. (2019) compare the outcomes of MEY and MSY, but within a PE framework, without considering the interactions between fishing and non-fishing sectors. The baseline simulation for MSY (MSY1) predicts that the harvest in the steady state is 16.5% larger (with aggregate welfare increasing by 98.9 billion KRW) compared to the status quo. In contrast, the baseline simulation for MEY (MEY1) predicts a 13.4% smaller harvest (with aggregate welfare decreasing by 385.6 billion KRW) than the status quo. Further, in most simulations for MSY, aggregate social welfare increases, while it decreases in most simulations for MEY. This finding aligns with arguments in previous studies that advocate for expanded fish production to enhance total societal benefits (Christensen, 2009; Sumaila and Hannesson, 2010; Squires and Vestergaard, 2016). As mentioned, it is reasonable to assume that Busan’s economy is moderately open. Therefore, the simulation results from MSY1 and MSY7-16 represent the most plausible outcome if MSY is implemented.

This study empirically demonstrates a trade-off between MEY and MSY. If fishery managers choose MEY over MSY, it will maximize the fishermen’s welfare and result in environmental benefits (i.e., higher level of biomass), but at the cost of the social welfare, under the most plausible assumptions about the openness of the economy. This study consistently shows that the increase in fishermen's welfare under MEY is considerably larger than under MSY across all simulations. On the other hand, if they choose MSY, it will increase the social welfare, but at the cost of the fishermen’s welfare. Fishermen often advocate for larger harvests, believing that this will yield larger economic benefits for them. In response, fishery managers may choose to increase the TAC to the level of MSY. However, this will reduce the fishermen’s welfare.

In the literature, MSY has been calculated without considering economic factors such as fish prices, input costs, and the broader economy. This study demonstrates that the GE model for MSY can evaluate the effects on important variables, such as prices, aggregate welfare, and output from non-fishing sectors—capabilities that a PE model for MSY lacks. This is important for fishery managers who wish to understand the implications of targeting MSY on these variables, as well as on effort, harvest, and stock.

Fishery managers often face a decision between two targets: MEY and MSY. This study suggests that, regardless of the target chosen, it is essential to use results from a GE model, as a PE model is unable to assess the impacts on non-fishing sectors and the broader societal benefits (Dalton et al., 2018). The only case in which a manager might rely on the PE-based MEY or MSY is if the economy is perfectly open, meaning that all prices remain constant. However, this is rarely the case in reality for several reasons: (i) many economies are not perfectly open, (ii) there are interactions between fishing and non-fishing sectors, and (iii) external factors, such as fluctuations in world fish prices or exchange rates, come into play. Even when PE-based MEY could be used with a perfectly open economy, the insights it provides are limited. Specifically, it cannot quantify the effects on the overall economy or aggregate welfare. As highlighted in this study, the impact of targeting either MEY or MSY can vary significantly depending on economic and ecological conditions. Since these conditions differ across regions and fisheries, calculating the effects is a highly empirical matter.

One innovative aspect of this study is its use of nested functions to determine the behavior of economic agents (producers, consumers, importers, and exporters). This approach provides flexibility in assigning different elasticities of substitution at various stages of the agents' decision-making process. This study carefully selected various elasticities based on previous econometric and other research, making adjustments as necessary for the Busan CGE model. However, some of these elasticities may not be suitable for other regions or fisheries. For instance, the effort and stock elasticities used in the fish harvest function may not accurately reflect the realities of fisheries in different areas. Consequently, studies addressing similar issues in fisheries elsewhere will need to appropriately assign the substitution elasticities governing the behaviors of economic agents specific to those areas.

The present study assumes that households and firms, other than the mackerel-producing firms, make their decisions (i.e., household consumption and firms' production) by maximizing current-period utility or minimizing current-period production costs, while mackerel-producing firms maximize their present discounted values of both present and future profits. In reality, when the fishing firms determine production in this manner, other sectors will respond to the fishing firms' decisions by adjusting their behavior based on predictions of present and future economic conditions. To develop a more comprehensive forward-looking CGE model, a future study could extend this research by specifying the dynamic behavior of these other sectors.

Further, the Busan CGE model used in this study is a single-region model. A single-region model has the limitation that it does not account for spillover effects to, and feedback effects from, other regions. When fishery management actions are implemented in Busan, the effects will not be limited to the region but will spill over to other regions. The effects occurring in these other regions will, in turn, have an impact on the original region (feedback effects) that may further alter the welfare of Busan residents. A future study will develop a multi-regional model to address this limitation.

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Table 1 Results from baseline simulation and alternative assumptions about the openness of the economy under MEY (MEY1-MEY6)

	MEY1 (Baseline simulation). PE model results are in parentheses.	MEY 2 Closed factor markets and highly inelastic trade	MEY 3 Closed factor markets and moderately elastic trade	MEY 4 Fixed total capital stock, perfectly mobile labor, and moderately elastic trade	MEY 5 Fixed total labor stock, perfectly mobile capital, and moderately elastic trade	MEY 6 (PE version) Highly open economy
Effects on fishing sector (% of pre-policy level, steady state)						
Ratio of stock to carrying capacity	0.753 (0.715)	0.786	0.753	0.753	0.753	0.715
Stock	141.6 (129.5)	152.1	141.6	141.7	141.6	129.5
Harvest	-13.4 (-5.1)	-21.6	-13.4	-13.4	-13.4	-5.1
Fish price	2.1	6.4	2.1	2.1	2.1	0
Rent	358.0 (343.9)	376.3	358.4	358.3	358.0	343.9
Effort	-56.3 (-47.3)	-64.0	-56.3	-56.3	-56.3	-47.3
Effort price	-0.0020	-0.1554	-0.0021	-0.0543	-0.0021	0
Aggregate change in non-fishing sectors over time						
Total non-fishing output (% of pre-policy level)	-0.014	0.110	0.097	0.184	0.003	-0.002
Total value-added in non-fishing sectors (billion KRW, discounted)	-225.7	696.6	989.5	1,753.3	-32.0	-84.6
Aggregate welfare change over time						
In billion KRW, discounted	-385.6	108.7	381.8	805.8	-272.3	-46.7
As % of pre-policy level of household expenditure	-0.043	0.012	0.043	0.091	-0.031	-0.005

Table 2 Results from sensitivity analyses for bioeconomic parameters under MEY (MEY1, MEY7-MEY10)

	MEY1 Baseline simulation	MEY7 Low stock elasticity	MEY8 High stock elasticity	MEY9 Low ratio of biomass to carrying capacity	MEY10 High ratio of biomass to carrying capacity
Effects on fishing sector (% of pre-policy level, steady state)					
Ratio of stock to carrying capacity	0.753	0.790	0.701	0.726	0.791
Stock	141.6	153.3	124.9	365.7	69.1
Harvest	-13.4	-22.6	-2.4	51.2	-33.5
Fish price	2.1	3.8	0.3	-5.1	6.3
Rent	358.0	168.9	577.0	639.0	259.9
Effort	-56.3	-42.4	-72.0	-28.6	-64.3
Effort price	-0.0020	-0.0015	-0.0026	-0.0010	-0.0022
Aggregate change in non-fishing sectors over time					
Total non-fishing output (% of pre-policy level)	-0.014	-0.024	-0.001	0.022	-0.030
Total value-added in non-fishing sectors (billion KRW, discounted)	-225.7	-320.6	-102.0	94.2	-364.3
Aggregate welfare change over time					
In billion KRW, discounted	-385.6	-657.5	-37.9	439.5	-718.0
As % of pre-policy level of household expenditure	-0.043	-0.074	-0.004	0.049	-0.081

Table 3 Results from baseline simulation and alternative assumptions about the openness of the economy under MSY (MSY1-MSY6)

	MSY1 (Baseline simulation). PE model results are in parentheses.	MSY2 Closed factor markets and highly inelastic trade	MSY3 Closed factor markets and moderately elastic trade	MSY4 Fixed total capital stock, perfectly mobile labor, and moderately elastic trade	MSY5 Fixed total labor stock, perfectly mobile capital, and moderately elastic trade	MSY6 (PE version) Highly open economy
Effects on fishing sector (% of pre-policy level, steady state)						
Ratio of stock to carrying capacity	0.5 (0.5)	0.5	0.5	0.5	0.5	0.5
Stock	60.4 (60.4)	60.4	60.4	60.4	60.4	60.4
Harvest	16.5 (16.5)	16.5	16.5	16.5	16.5	16.5
Fish price	-2.0	-3.4	-2.0	-2.0	-2.0	0
Rent	179.3 (201.3)	165.1	179.3	179.3	179.3	201.3
Effort	-5.8 (-5.8)	-5.8	-5.8	-5.8	-5.8	-5.8
Effort price	-0.0002	-0.0093	-0.0069	-0.0019	-0.0002	0
Aggregate change in non-fishing sectors over time						
Total non-fishing output (% of pre-policy level)	0.006	0.012	0.019	0.038	0.002	0.01
Total value-added in non-fishing sectors (billion KRW, discounted)	-1.3	139.1	270.8	478.2	11.4	54.8
Aggregate welfare change over time						
In billion KRW, discounted	98.9	115.6	272.3	387.4	106.3	162.2
As % of pre-policy level of household expenditure	0.011	0.013	0.031	0.044	0.012	0.018

Table 4 Results from sensitivity analyses for bioeconomic parameters under MSY (MSY1, MSY7-MSY10).

-	MSY1 Baseline simulation	MSY7 Low stock elasticity	MSY8 High stock elasticity	MSY9 Low ratio of biomass to carrying capacity	MSY10 High ratio of biomass to carrying capacity
Effects on fishing sector (% of pre-policy level, steady state)					
Ratio of stock to carrying capacity	0.5	0.5	0.5	0.5	0.5
Stock	60.4	60.4	60.4	220.8	6.9
Harvest	16.5	16.5	16.5	90.0	0.4
Fish price	-2.0	-2.0	-2.0	-7.4	-0.1
Rent	179.3	68.4	361.3	421.9	33.9
Effort	-5.8	7.6	-27.9	34.0	-3.7
Effort price	-0.0002	0.0003	-0.0010	0.0014	-0.0001
Aggregate change in non-fishing sectors over time					
Total non-fishing output (% of pre-policy level)	0.006	0.004	0.009	0.035	0.0001
Total value-added in non-fishing sectors (billion KRW, discounted)	-1.3	-16.3	23.2	241.0	-8.4
Aggregate welfare change over time					
In billion KRW, discounted	98.9	28.0	215.0	824.0	-3.6
As % of pre-policy level of household expenditure	0.011	0.003	0.025	0.093	-0.0004

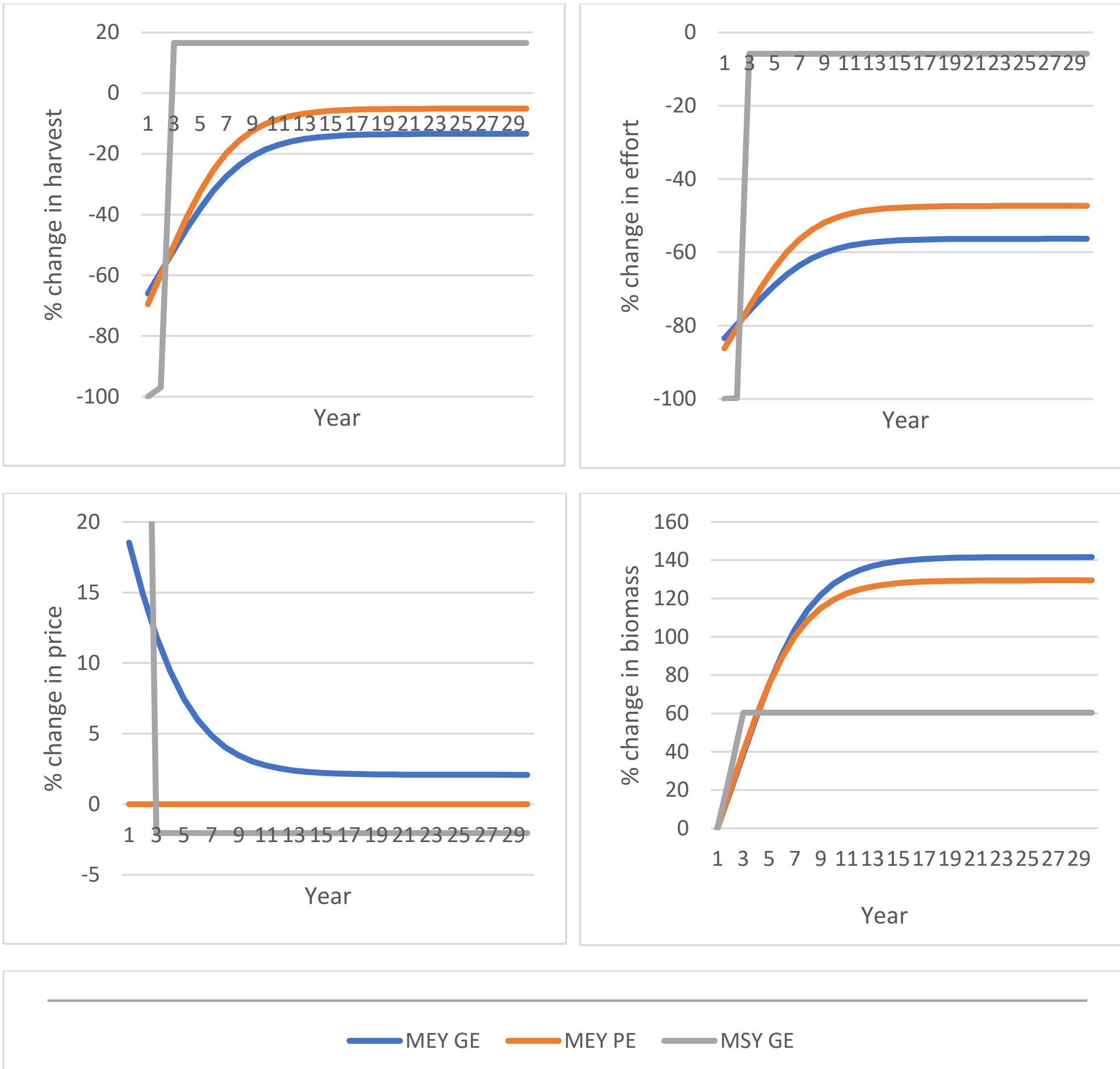

Figure 1 Percentage changes in harvest (top left), effort (top right), price (bottom left), and biomass (bottom right). Trajectories labeled MEY GE, MEY PE, and MSY GE represent GE-based MEY (MEY1), PE-based MEY, and GE-based MSY (MSY1), respectively.

ONLINE APPENDICES

Appendix A

Table A.1 List of Industries in the Busan CGE Model

Industry Number	Industry Name
1	Agriculture and Forestry
2	Mackerel Harvesting
3	Non-mackerel Harvesting
4	Aquaculture
5	Mining
6	Food and Beverage Manufacturing
7	Seafood Processing
8	Textile and Leather Products Manufacturing
9	Wood and Paper Production and Printing
10	Coal and Petroleum Production
11	Chemical Products Manufacturing
12	Non-metallic Mineral Products Manufacturing
13	Production of Primary Metal Products
14	Metalworking
15	Production of Computers, Electronics, and Precision Instruments
16	Electrical Equipment Manufacturing
17	Machinery Manufacturing
18	Transportation Equipment Manufacturing
19	Other Manufacturing
20	Manufacturing Services
21	Production of Electricity, Gas, and Steam
22	Water Supply, Sewerage, and Waste Management
23	Construction
24	Wholesale and Retail Trade
25	Transportation
26	Food Service and Lodging
27	Telecommunications and Broadcasting
28	Finance and Insurance
29	Real Estate Services
30	Professional, Scientific, and Technical Services
31	Business Support
32	Public Administration and National Defense
33	Educational Services
34	Health and Social Services
35	Arts, Sports, and Leisure Services
36	Other Services

Table A.2 Structure of Social Accounting Matrix for the Busan CGE Model

	Activity	Commodity	Value-added	Households	Regional Govt.	National Govt.	Savings-Investment	Rest of the World
Activity		Gross Output						
Commodity	Intermediate Inputs			Household Demand	Regional Govt. Demand	National Govt. Demand	Investment Demand	Exports
Value-added	Value-added							
Households			Factor Income		Regional Govt. Transfers			
Regional Govt.			Indirect Business Tax	Household Taxes		National Govt. Transfers		
National Govt.			Indirect Business Tax, Corporate Income Tax	Personal Income Tax				
Savings-Investment			Business Savings	Household Savings	Regional Govt. Savings	National Govt. Savings		External Savings
Rest of the World		Imports	Factor Income Leakage	Household Income Leakage				

Table A.3 Simulations and sensitivity analyses

Type of simulation / sensitivity analysis	Simulation Name	Description
		Status quo
Replication of base-year data	SQ	Solve for the status quo (regulated open access) with baseline assumptions and parameters
		MEY
Baseline	MEY1	Solve for MEY with baseline assumptions and parameters. Baseline simulation for MEY
Openness assumption	MEY2	Solve for MEY with closed factor markets and highly inelastic trade
	MEY3	Solve for MEY with closed factor markets and moderately elastic trade
	MEY4	Solve for MEY with fixed total capital stock, perfectly mobile labor, and moderately elastic trade
	MEY5	Solve for MEY with fixed total labor stock, perfectly mobile capital, and moderately elastic trade
	MEY6	Solve for MEY with perfectly mobile factors and highly elastic trade. PE version.
Bioeconomic parameter	MEY7	The same as MEY1 with low stock elasticity
	MEY8	The same as MEY1 with high stock elasticity
	MEY9	The same as MEY1 with low ratio of initial biomass to carrying capacity
	MEY10	The same as MEY1 with high ratio of initial biomass to carrying capacity
	MEY11	The same as MEY1 with low intrinsic growth rate
	MEY12	The same as MEY1 with high intrinsic growth rate
	MEY13	The same as MEY1 with low Armington elasticity for mackerel
	MEY14	The same as MEY1 with high Armington elasticity for mackerel
	MEY15	The same as MEY1 with low discount rate
	MEY16	The same as MEY1 with high discount rate
		MSY
Baseline	MSY1	Solve for MSY with baseline assumptions and parameters. Baseline simulation for MSY
Openness assumption	MSY2	Solve for MSY with closed factor markets and highly inelastic trade
	MSY3	Solve for MSY with closed factor markets and moderately elastic trade
	MSY4	Solve for MSY with fixed total capital stock, perfectly mobile labor, and moderately elastic trade
	MSY5	Solve for MSY with fixed total labor stock, perfectly mobile capital, and moderately elastic trade
	MSY6	Solve for MSY with perfectly mobile factors and highly elastic trade. PE version.
Bioeconomic parameter	MSY7	The same as MSY1 with low stock elasticity
	MSY8	The same as MSY1 with high stock elasticity
	MSY9	The same as MSY1 with low ratio of initial biomass to carrying capacity
	MSY10	The same as MSY1 with high ratio of initial biomass to carrying capacity
	MSY11	The same as MSY1 with low intrinsic growth rate
	MSY12	The same as MSY1 with high intrinsic growth rate
	MSY13	The same as MSY1 with low Armington elasticity for mackerel
	MSY14	The same as MSY1 with high Armington elasticity for mackerel
	MSY15	The same as MSY1 with low discount rate
	MSY16	The same as MSY1 with high discount rate

Appendix B Busan CGE model and parameterization

B.1 List of equations, variables, and parameters

This section presents equations, variables, and parameters used in the baseline simulation for MEY (MEY1) in the Busan CGE model. The equations presented in this section were used to perform the baseline simulation.

B.1.1 List of Equations

In the equations below, *i* and *j* denote production sectors (activities); *fs*, *sp*, and *nsp* denote fish harvesting sectors, seafood processing sector, and all the other sectors, respectively; *nfs* denote non-fish harvesting sectors; *mc* and *nmc* denote mackerel and non-mackerel fishing sectors, respectively; *c* and *d* denote commodities; *nfc* denotes non-food commodity; *rf* denotes raw fish commodity. Subscript *t* denoting period (time) is suppressed for simplicity in the equations except in the objective function and the population dynamics equation (Equations 13 and 100 below).

PRICES

Definition of regional price for imports from foreign countries: second stage

$$PM_c = PWM_c ER \tag{1}$$

Definition of regional price of exports to foreign countries: second stage

$$PE_c = PWE_c ER \tag{2}$$

Definition of price of the composite good consisting of domestic- and foreign-sourced goods: second stage

$$PQ_c Q_c = PDPM_c \cdot DPM_c + PM_c \cdot M_c \tag{3}$$

Definition of the price of the composite good consisting of ROC- and regionally sourced goods: third stage

$$PDPM_c DPM_c = PMD_c \cdot MDOM_c + PD_c \cdot D_c \tag{4}$$

Definition of sales price (weighted average of the prices of goods supplied to domestic regions and foreign countries): second stage

$$PZ_c \cdot Z_c = PDPE_c DPE_c + PE_c \cdot E_c \tag{5}$$

Definition of sales price (weighted average of the prices of goods supplied to ROC and the study region): third stage

$$PDPE_c \cdot DPE_c = PD_c D_c + PED_c \cdot EDOM_c \tag{6}$$

Definition of regional industry prices:

$$PX_i = \sum_c \Delta_{i,c} PZ_c \tag{7}$$

Definition of value-added price:

$$PV_i = PX_i - \sum_c \frac{INTT_{c,i}}{X_i} PQ_c - itr_i PX_i - rcfk_i PX_i \qquad (8)$$

Definition of activity price:

$$PVV_i = PV_i + \sum_c \frac{INTT_{c,i}}{X_i} PQ_c \qquad (9)$$

PRODUCTION AND INPUT DEMAND

Fish harvesting industries

First stage

Harvesting function:

$$X_{fs} = f(E_{fs}) = d_{fs} E_{fs}^{\ f_{fs}} N_{fs}^{\ g_{fs}} \qquad (10)$$

Output transformation function:

$$X_{fs} = ucp_{fs} \cdot HARV_{fs} \qquad (11)$$

Effort demand function (regulated open access fishery, non-mackerel fishery)

$$\frac{k_{nmc}\,(PVV_{nmc} - EPP_{nmc}) X_{nmc}}{E_{nmc}} = C1_{nmc} \qquad (12)$$

Objective function (mackerel fishery)

$$\text{Max } OBJ = \sum_t^T \frac{1}{(1+d)^t} \left(PVV_{mc,t} H_{mc,t} - C_{mc,t} E_{mc,t} \right) \qquad (13)$$

Level of stock in the first period:

$$N_{mc,TF} = N_{mc,0} \qquad (14)$$

Last period condition:

$$HARV_{mc,TL} = N_{mc,TL} + \gamma_{mc} N_{mc,TL} \left(1 - \frac{N_{mc,TL}}{KC_{mc}} \right) \qquad (15)$$

Second stage

Demand for labor and capital aggregate

$$LAK_{fs} = \left(\frac{E_{fs}}{\psi 1_{fs}} \right) \left[\frac{\alpha 1_{fs} \psi 1_{fs} C1_{fs}}{PLK_{fs}} \right]^{\sigma 1_{fs}} \qquad (16)$$

Demand for intermediate input aggregate

$$INT_{fs} = \left(\frac{E_{fs}}{\psi 1_{fs}} \right) \left[\frac{\left((1-\alpha 1_{fs}\right) \psi 1_{fs} C1_{fs}}{PINT_{fs}} \right]^{\sigma 1_{fs}} \qquad (17)$$

Unit cost of effort:

$$C1_{fs} = \frac{1}{\psi 1_{fs}}\left[\alpha 1_{fs}{}^{\sigma 1_{fs}}\left(PLK_{fs}\right)^{(1-\sigma 1_{fs})} + (1-\alpha 1_{fs})^{\sigma 1_{fs}}\left(PINT_{fs}\right)^{(1-\sigma 1_{fs})}\right]^{\frac{1}{(1-\sigma 1_{fs})}} \quad (18)$$

<u>Third stage – value added</u>

Demand for labor:

$$L_{fs} = \left(\frac{LAK_{fs}}{\psi 2_{fs}}\right)\left[\frac{(1-\alpha 2_{fs})\psi 2_{fs} C2_{fs}}{W}\right]^{\sigma 2_{fs}} \quad (19)$$

Demand for capital:

$$K_{fs} = \left(\frac{LAK_{fs}}{\psi 2_{fs}}\right)\left[\frac{\alpha 2_{fs}\psi 2_{fs} C2_{fs}}{R}\right]^{\sigma 2_{fs}} \quad (20)$$

Unit cost function:

$$C2_{fs} = \frac{1}{\psi 2_{fs}}\left[(1-\alpha 2_{fs})^{\sigma 2_{fs}}(W)^{(1-\sigma 2_{fs})} + \alpha 2_{fs}{}^{\sigma 2_{fs}}(R)^{(1-\sigma 2_{fs})}\right]^{\frac{1}{(1-\sigma 2_{fs})}} \quad (21)$$

Cost of labor and capital aggregate:

$$PLK_{fs}LAK_{fs} = W \cdot L_{fs} + R_{fs} \cdot K_{fs} \quad (22)$$

<u>Third stage – intermediate input composite</u>

Demand for intermediate input:

$$INTT_{c,fs} = \left(\frac{INT_{fs}}{\psi 3_{fs}}\right)\left[\frac{\alpha 3_{fs}\psi 3_{fs} C3_{fs}}{PQ_c}\right]^{\sigma 3_{fs}} \quad (23)$$

Unit cost of intermediate composite:

$$C3_{fs} = \frac{1}{\psi 3_{fs}}\left[\sum_c \alpha 3_{fs}{}^{\sigma 3_{fs}}(PQ_c)^{(1-\sigma 3_{fs})}\right]^{\frac{1}{(1-\sigma 3_{fs})}} \quad (24)$$

Cost of composite intermediate input:

$$PINT_{fs}INT_{fs} = \sum_c PQ_c \cdot INTT_{c,fs} \quad (25)$$

Non-fishing industries

<u>First stage</u>

Demand for labor and capital aggregate:

$$LAK_{nfs} = \left(\frac{X_{nfs}}{\psi 1_{nfs}}\right)\left[\frac{\alpha 1_{nfs}\psi 1_{nfs} C1_{nfs}}{PLK_{nfs}}\right]^{\sigma 1_{nfs}} \quad (26)$$

Demand for intermediate aggregate

$$INT_{nfs} = \left(\frac{X_{nfs}}{\psi 1_{nfs}}\right)\left[\frac{((1-\alpha 1_{nfs})\psi 1_{nfs} C1_{nfs}}{PINT_{nfs}}\right]^{\sigma 1_{nfs}} \quad (27)$$

Unit cost of the composite input of labor, capital, and intermediate inputs:

$$C1_{nfs} = \frac{1}{\psi 1_{nfs}}\left[\alpha 1_{nfs}{}^{\sigma 1_{nfs}}\left(PLK_{nfs}\right)^{(1-\sigma 1_{nfs})} + (1-\alpha 1_{nfs})^{\sigma 1_{fs}}\left(PINT_{nfs}\right)^{(1-\sigma 1_{nfs})}\right]^{\frac{1}{(1-\sigma 1_{nfs})}} \tag{28}$$

Zero profit condition:

$$PVV_{nfs}X_{nfs} = PLK_{nfs} \cdot LAK_{nfs} + PINT_{nfs} \cdot INT_{nfs} \tag{29}$$

<u>Second stage – value added</u>

Demand for labor:

$$L_{nfs} = \left(\frac{LAK_{nfs}}{\psi 2_{nfs}}\right)\left[\frac{(1-\alpha 2_{nfs})\psi 2_{nfs}C2_{nfs}}{W}\right]^{\sigma 2_{nfs}} \tag{30}$$

Demand for capital:

$$K_{nfs} = \left(\frac{LAK_{nfs}}{\psi 2_{nfs}}\right)\left[\frac{\alpha 2_{nfs}\psi 2_{nfs}C2_{nfs}}{R}\right]^{\sigma 2_{nfs}} \tag{31}$$

Unit cost of labor and capital aggregate:

$$C2_{nfs} = \frac{1}{\psi 2_{nfs}}\left[(1-\alpha 2_{nfs})^{\sigma 2_{nfs}}(W)^{(1-\sigma 2_{nfs})} + \alpha 2_{nfs}{}^{\sigma 2_{nfs}}(R)^{(1-\sigma 2_{nfs})}\right]^{\frac{1}{(1-\sigma 2_{nfs})}} \tag{32}$$

Cost of labor and capital aggregate:

$$PLK_{nfs}LAK_{nfs} = W \cdot L_{nfs} + R_{nfs} \cdot K_{nfs} \tag{33}$$

<u>Second stage – intermediate input composite</u>

Demand for intermediate input:

$$INTT_{c,fs} = \left(\frac{INT_{nfs}}{\psi 3_{nfs}}\right)\left[\frac{\alpha 3_{nfs}\psi 3_{nfs}C3_{nfs}}{PQ_c}\right]^{\sigma 3_{nfs}} \tag{34}$$

Unit cost of intermediate input composite

$$C3_{nfs} = \frac{1}{\psi 3_{nfs}}\left[\sum_c \alpha 3_{nfs}{}^{\sigma 3_{nfs}}(PQ_c)^{(1-\sigma 3_{nfs})}\right]^{\frac{1}{(1-\sigma 3_{nfs})}} \tag{35}$$

Cost of composite intermediate input:

$$PINT_{nfs}INT_{nfs} = \sum_c PQ_c \cdot INTT_{c,nfs} \tag{36}$$

Definition of regional commodity output:

$$Z_c = \sum_i \Delta_{i,c} X_i \tag{37}$$

HOUSEHOLD DEMAND

First stage

Demand for composite food commodity:

$$FD \quad = \frac{\beta\, DYH}{P_{FD}{}^{\mu}\left[\beta P_{FD}{}^{(1-\mu)} + \ (1-\beta)\, P_{NFD}{}^{(1-\mu)}\right]} \tag{38}$$

Demand for composite non-food commodity:

$$NFD = \frac{(1-\beta)\, DYH}{P_{NFD}{}^{\mu}\left[\beta P_{FD}{}^{(1-\mu)} + \ (1-\beta)\, P_{NFD}{}^{(1-\mu)}\right]} \tag{39}$$

Unit expenditure:

$$PAA = \left[\beta P_{FD}{}^{(1-\mu)} + \ (1-\beta)\, P_{NFD}{}^{(1-\mu)}\right]^{\frac{1}{1-\mu}} \tag{40}$$

Budget constraint:

$$DYH = PAA \cdot AA \tag{41}$$

Second stage: composite seafood vs. composite non-seafood food

Demand for composite seafood commodity:

$$SFD \quad = \frac{\beta 1\, DYH1}{PSFD^{\mu 1}\left[\beta 1\, PSFD^{(1-\mu 1)} + (1-\beta 1)\, PNSFD^{(1-\mu 1)}\right]} \tag{42}$$

Demand function for composite non-seafood food commodity:

$$NSFD \quad = \frac{(1-\beta 1)\, DYH1}{PNSFD^{\mu 1}\left[\beta 1\, PSFD^{(1-\mu 1)} + (1-\beta 1)\, PNSFD^{(1-\mu 1)}\right]} \tag{43}$$

Unit expenditure:

$$PQF = \left[\beta 1\, PSFD^{(1-\mu 1)} + (1-\beta 1)\, PNSFD^{(1-\mu 1)}\right]^{\frac{1}{1-\mu 1}} \tag{44}$$

Budget constraint:

$$DYH1 = PQF \cdot FD \tag{45}$$

Second stage: composite nonfood

Demand for nonfood commodities:

$$NF_{nfc} = \frac{\beta 2_{nfc} DYH2}{PQNF_{nfc}{}^{\mu 2}\ \sum_{nfc} \beta 2_{nfc} PQNF_{nfc}{}^{\mu 2}} \tag{46}$$

Unit expenditure for composite nonfood commodity:

$$PQN = \left[\sum_{nfc} \beta 2_{nfc} PQNF_{nfc}{}^{\mu 2}\right]^{\frac{1}{1-\mu 2}} \tag{47}$$

Budget constraint:

$$DYH2 = PQN \cdot NFD \tag{48}$$

Third stage

Demand for composite raw fish commodity:

$$RFISH \quad = \frac{\beta 3 \;\; DYH3}{PRFISH^{\mu 3} \left[\beta 3 \; PRFISH^{(1-\mu 3)} + (1-\beta 3) PPFISH^{(1-\mu 3)} \right]} \tag{49}$$

Demand for processed seafood commodity:

$$PFISH \quad = \frac{(1-\beta 3) \; DYH3}{PPFISH^{\mu 3} \left[\beta 3 \; PRFISH^{(1-\mu 3)} + (1-\beta 3) PPFISH^{(1-\mu 3)} \right]} \tag{50}$$

Unit expenditure:

$$PQS = \left[\beta 3 \; PRFISH^{(1-\mu 3)} + (1 - \; \beta 3) PPFISH^{(1-\mu 3)} \right]^{\frac{1}{1-\mu 3}} \tag{51}$$

Budget constraint:

$$DYH3 = \; PQS \cdot SFD \tag{52}$$

Fourth stage

Demand for raw fish:

$$RF_{rf} \; = \frac{\beta 4_{rf} \; DYH4}{{PQRF_{rf}}^{\mu 4} \; \sum_{rf} \beta 4_{rf} \; {PQRF_{rf}}^{\mu 4}} \tag{53}$$

Unit expenditure:

$$PQR = \; \left[\sum_{rf} \beta 4_{rf} \; {PQRF_{rf}}^{\mu 4} \right]^{\frac{1}{1-\mu 4}} \tag{54}$$

Budget constraint:

$$DYH4 = \; PQR \cdot RFISH \tag{55}$$

Other equations

Relationship between the variables in the nested utility function and household consumption variables:

$$NF_{nfc} = HC_{nfc} \tag{56}$$
$$PQNF_{nfc} = PQ_{nfc} \tag{57}$$
$$NSFD = HC_{commodity\ 6} \tag{58}$$
$$PNSFD = PQ_{commodity\ 6} \tag{59}$$
$$PFISH = HC_{commodity\ 7} \tag{60}$$
$$PPFISH = PQ_{commodity\ 7} \tag{61}$$
$$RNF_{rf} = HC_{rf} \tag{62}$$
$$PQRF_{rf} = PQ_{rf} \tag{63}$$

EXPORTS

Second stage: foreign exports vs. supply to domestic regions

Supply aggregation function:

$$Z_c = A_c^T\left[\varphi_c \, {EX_c}^{\theta_c} + (1-\varphi_c){DPE_c}^{\theta_c}\right]^{\frac{1}{\theta_c}} \tag{64}$$

Export supply function:

$$EX_c = \left(\frac{PE_c}{PDPE_c}\right)^{\Lambda_c}\left(\frac{1-\varphi_c}{\varphi_c}\right)^{\Lambda_c} DPE_c \tag{65}$$

Third stage: Domestic exports vs. regional supply

Supply aggregation function:

$$PDPE_c = A1_c^T\left[\varphi1_c \, {EDOM_c}^{\theta1_c} + (1-\varphi1_c){D_c}^{\theta1_c}\right]^{\frac{1}{\theta1_c}} \tag{66}$$

Export supply function:

$$EDOM_c = \left(\frac{PED_c}{PD_c}\right)^{\Lambda1_c}\left(\frac{1-\varphi1_c}{\varphi1_c}\right)^{\Lambda1_c} D_c \tag{67}$$

Export demand function:

$$EDOM_c = sfte_c \cdot \overline{EDOM_c} \cdot \left(\frac{1}{PEDOM_c}\right)^{\tau_c} \tag{68}$$

IMPORTS

Second stage (foreign imports vs. domestic supply)

Demand aggregation function:

$$Q_c = A_c^C\left[\delta_c \, {M_c}^{-\rho_c} + (1-\delta_c){DPM_c}^{-\rho_c}\right]^{-\frac{1}{\rho_c}} \tag{69}$$

Import demand function:

$$M_c = \left(\frac{PDPM_c}{PM_c}\right)^{\nu_c}\left(\frac{1-\delta_c}{\delta_c}\right)^{\nu_c} DPM_c \tag{70}$$

Third stage (domestic imports vs. regional supply)

$$DPM_c = A1_c^C\left[\delta1_c \, {MDOM_c}^{-\rho_c} + (1-\delta1_c){D_c}^{-\rho1_c}\right]^{-\frac{1}{\rho1_c}} \tag{71}$$

Import demand function:

$$MDOM_c = \left(\frac{PD_c}{PMD_c}\right)^{\nu1_c}\left(\frac{1-\delta1_c}{\delta1_c}\right)^{\nu_c} D_c \tag{72}$$

Import supply function:

$$MDOM_c = sftm_c \cdot \overline{MDOM_c} \cdot (PMDOM_c)^{\gamma_c} \tag{73}$$

INCOME BLOCK

Total labor income:
$YL = \sum_i W \cdot L_i + \sum_{fs} \theta_L (1 - k_{fs}) PV_{fs} X_{fs}$ (74)

Total capital income:
$YK = \sum_i R \cdot K_i + \sum_{fs} \theta_K (1 - k_{fs}) PV_{fs} X_{fs}$ (75)

Labor income after leakage:
$YLL = (1 - wleakr) YL$ (76)

Capital income after leakage, national and regional taxes, and enterprise savings:
$YKK = (1 - rleakr - ktrng - ktrrg - esrate) YK$ (77)

Household factor income:
$YH = YLL + YKK$ (78)

Total household income:
$TYH = YH + RTR + REMH$ (79)

Household expenditure:
$DYH = (1 - trng - trrg - MPS) \cdot TYH$ (80)

NATIONAL AND REGIONAL GOVERNMENTS

National government revenue:
$NGREV = ngibt \sum_i (itr_i) PX_i X_i + (ktrng) YK + trng \cdot TYH$ (81)

National government expenditure:
$NGEXP = \sum_c PQ_c CNG_c + TRANR$ (82)

National government demand for commodities:
$PQ_c CNG_c = (ngles_c) NGDTOT$ (83)

Regional government revenue:
$RGREV = ribt \sum_i (itr_i) PX_i X_i + (ktrrg) YK + trng \cdot TYH + TRANR$ (84)

Regional government expenditure:
$RGEXP = \sum_c PQ_c CRG_c + RTR$ (85)

Regional government demand for commodities:
$PQ_c CRG_c = (rgles_c) RGDTOT$ (86)

National government transfer to regional government:
$TRANR = (nrrat) \cdot NGREV$ (87)

SAVINGS AND INVESTMENT

Household savings:
$$HSAV = MPS \cdot TYH \tag{88}$$

Enterprise savings:
$$ENTSAV = (esrate) \cdot YK \tag{89}$$

National government savings:
$$GSN = NGREV - NGEXP \tag{90}$$

Regional government savings:
$$GSR = RGREV - RGEXP \tag{91}$$

External savings:
$$FSAV = \sum_c PM_c M_c - \sum_c PE_c EX_c + (wleakr)YL + (rleakr)YK - REMH \tag{92}$$

Total savings:
$$TSAV = HSAV + ENTSAV + GSN + GSR + (ER)FSAV \tag{93}$$

Investment by sector of origin:
$$ID_c = \frac{(invrat_c)\, ITOT}{PQ_c} \tag{94}$$

EQUILIBRIUM CONDITIONS

Goods market equilibrium:
$$Q_c = \sum_h HC_{c,h} + \sum_i ND_{c,i} + ID_c + CNG_c + CRG_c \tag{95}$$

Labor market equilibrium condition:
$$LTOT_i = \sum_i L_i \tag{96}$$

Capital market equilibrium condition:
$$R = RB \tag{97}$$

GROSS REGIONAL PRODUCT

Gross regional product at market prices:
$$GRP = \sum_i [PV_i X_i + itr_i PX_i X_i] \tag{98}$$

Real gross regional product:
$$RGRP = \sum_c [HC_c + ID_c + CNG_c + CRG_c + EX_c - M_c] \tag{99}$$

MODEL CLOSURE

The following variables are fixed at their base-year levels: ER, NGDTOT, N_{fs}, ITOT, LTOT, R, and RGDTOT.

STOCK GROWTH

Logistic growth function:

$$N_{t+1} = N_t + \gamma N_t \left(1 - \frac{N_t}{KC}\right) - HARV_t \ , \qquad (100)$$

B.1.2 List of Endogenous Variables

AA	Composite of all commodities consumed by household
$C1_{fs}$	Unit cost of fish harvesting effort in sector *fs* (stage 2)
$C2_{fs}$	Unit cost of capital and labor aggregate in sector *fs* (stage 3)
$C3_{fs}$	Unit cost of aggregate intermediate input in sector *fs* (stage 3)
$C1_{nfs}$	Unit cost of the composite input of labor, capital, and intermediate inputs in sector *nfs* (stage 1)
$C2_{nfs}$	Unit cost of capital and labor aggregate in sector *nfs* (stage 2)
$C3_{nfs}$	Unit cost of aggregate intermediate input in sector *nfs* (stage 2)
CNG_c	National government demand for commodity *c*
CRG_c	Regional government demand for commodity *c*
D_c	Quantity of locally produced and consumed commodity *c*
DPE_c	Quantity of commodity *c* that is produced locally and consumed domestically
DPM_c	Quantity of domestically produced and locally consumed commodity *c*
DYH	Household's total expenditure (disposable income)
DYH1	Household's total expenditure on the composite food commodity
DYH2	Household's total expenditure on the composite non-food commodity
DYH3	Household's total expenditure on the composite seafood commodity
DYH4	Household's total expenditure on the composite raw fish commodity
E_{fs}	Effort in fish harvest function
$EDOM_c$	Quantity of commodity *c* that is produced locally and consumed in ROC
ENTSAV	Enterprise savings
EPP_{fs}	Marginal surplus of producing another unit of output in fish harvesting sectors
ER	Exchange rate
EX_c	Quantity of commodity *c* exported to foreign countries
FD	Composite food commodity consumed by household
FSAV	External savings
GRP	Gross regional product at market prices
GSN	National government savings
GSR	Regional government savings
$HARV_{fs}$	Quantity of fish caught in tons
HC_c	Household's demand for commodity *c*
HSAV	Household savings
ID_c	Aggregate investment demand for commodity *c*
INT_i	Aggregate intermediate input use in industry *i*

$INTT_{c,i}$	Quantity of intermediate input *c* used in industry *i*
ITOT	Total value of investment in the economy
K_i	Level of capital in sector *i*
KTOT	Total capital stock in the economy
L_i	Labor employment in sector *i*
LAK_i	Composite input of labor and capital
LTOT	Aggregate labor demand
M_c	Quantity of commodity *c* imported from foreign countries to the study region
$MDOM_c$	Quantity of commodity *c* produced in ROC that is imported to the study region
N_{fs}	Fish population
$ND_{c,i}$	Quantity of intermediate commodity *c* used by sector *i*
NF_{nfc}	Household's consumption of non-food commodity *nfc*
NFD	Composite non-food commodity consumed by household
NGDTOT	National government expenditure on commodities
NGEXP	Total national government expenditure
NGREV	National government revenue
NSFD	Composite non-seafood food commodity consumed by household
PAA	Unit expenditure on aggregate commodity consumed by household
PD_c	Price of locally produced and consumed commodity *c*
$PDPE_c$	Price of commodity *c* that is produced locally and consumed domestically
$PDPM_c$	Price of domestically produced and locally consumed commodity *c*
PE_c	Price of commodity *c* exported to foreign countries
PED_c	Price of commodity *c* that is produced locally and consumed in ROC
PFISH	Processed seafood consumption by household
$PINT_i$	Price of composite input of intermediates
PLK_i	Price of the composite input of labor and capital
PM_c	Price of commodity *c* imported from foreign countries
PMD_c	Price of commodity *c* produced in ROC that is imported to the study region
PQ_c	Price of composite commodity *c*
PQF	Price of the composite food commodity consumed by household
PQN	Price of the composite non-food commodity consumed by household
PQR	Price of the composite raw fish commodity consumed by household
PQS	Price of the composite seafood commodity consumed by household
PV_i	Net price of a unit of value-added in sector *i*
PVV_i	Cost of primary and intermediate inputs used to produce a unit of sector *i*'s output
PX_i	Output price of good *i*
PZ_c	Price of commodity *c* produced in the region
RF_{rf}	Consumption of raw fish *rf* by household
RFISH	Composite raw fish consumption by household
Q_c	Quantity of composite commodity *c*
RGRP	Real gross regional product
RGEXP	Total regional government expenditures
RGREV	Regional government revenue
RGDTOT	Regional government expenditures on commodities
SFD	Composite seafood commodity consumed by household

TRANR	National government transfers to regional government
TSAV	Total savings
TYH	Total household income
W	Market wage rate
X_i	Industry output in sector *i*
YH	Household's factor income
YK	Total capital income
YKK	Capital income after leakage, national and regional taxes, and enterprise savings
YL	Total labor income
YLL	Labor income after leakage
Z_c	Output of commodity *c*

B.1.3 List of Exogenous Variables

$\overline{EDOM_c}$	Base-year quantity of commodity *c* that is produced locally and consumed in ROC
$\overline{MDOM_c}$	Base-year quantity of commodity *c* produced in ROC that is imported to study region
REMH	Remittances from the rest of the world
RTR	Regional government transfers to household
PWE_i	Rest of world price of good *i* exported to foreign countries
PWM_i	Rest of world price of good *i* imported from foreign countries

B.1.4 List of Parameters

Production

$\Delta_{i,c}$	Row-sum normalized make matrix
$a_{c,i}$	Technical coefficients
$\alpha 1_{fs}$	Effort function share parameter for fishing industries
$\alpha 2_{fs}$	Value-added function share parameter for fishing industries
$\alpha 3_{fs}$	Share parameter in intermediate input aggregation function for fishing industries
$\alpha 1_{nfs}$	Production function share parameter for non-fishing industries
$\alpha 2_{nfs}$	Value-added function share parameter for non-fishing industries
$\alpha 3_{nfs}$	Share parameter in intermediate input aggregation for non-fishing industries
$\sigma 1_{fs}$	Effort function exponent for fishing industries
$\sigma 2_{fs}$	Value-added function exponent for fishing industries
$\sigma 3_{fs}$	Exponent in intermediate input aggregation function for fishing industries
$\sigma 1_{nfs}$	Production function exponent for non-fishing industries
$\sigma 2_{nfs}$	Value-added function exponent for non-fishing industries
$\sigma 3_{nfs}$	Exponent in intermediate input aggregation for non-fishing industries
$\psi 1_{fs}$	Effort function shift parameter for fishing industries
$\psi 2_{fs}$	Value-added function shift parameter for fishing industries
$\psi 3_{fs}$	Shift parameter in intermediate input aggregation function for fishing industries
$\psi 1_{nfs}$	Production function shift parameter for non-fishing industries
$\psi 2_{nfs}$	Value-added function shift parameter for non-fishing industries
$\psi 3_{nfs}$	Shift parameter in intermediate input aggregation for non-fishing industries

θ_L	Share of resource rent received by labor
θ_K	Share of resource rent received by capital
itr_i	Indirect tax rates
f_{fs}	Effort elasticity in fish harvest function
g_{fs}	Stock elasticity in fish harvest function
d_{fs}	Shift parameter (catchability coefficient) in fish harvest function
k_{fs}	Parameter measuring the degree of openness of the fishery
$rcfk_i$	Rate of consumption of fixed capital
ucp_{fs}	Parameter that changes fish harvest from tons to value

<u>Import Demand</u>

A_c^C	Armington function shift parameter: second stage
δ_c	Armington function share parameter: second stage
ρ_c	Armington function exponent: second stage
υ_c	Elasticity of substitution between imports and local goods: second stage
$A1_c^C$	Armington function shift parameter: third stage
$\delta 1_c$	Armington function share parameter: third stage
$\rho 1_c$	Armington function exponent: third stage
$\upsilon 1_c$	Elasticity of substitution: third stage

<u>Import Supply (third stage)</u>

$sftm_c$	Shift parameter in import supply function
γ_c	Elasticity of import supply with respect to price

<u>Export Supply</u>

A_c^T	CET function shift parameter: second stage
φ_c	CET function share parameter: second stage
θ_c	CET function exponent: second stage
Λ_c	Elasticity of transformation: second stage
$A1_c^T$	CET function shift parameter: third stage
$\varphi 1_c$	CET function share parameter: third stage
$\theta 1_c$	CET function exponent: third stage
$\Lambda 1_c$	Elasticity of transformation: third stage

<u>Export Demand (third stage)</u>

$sfte_c$	Shift parameter in export demand function
τ_c	Elasticity of export demand with respect to price

<u>Consumption</u>

β	Expenditure share for composite food commodity consumed by household
μ	Elasticity of substitution between composite food commodity and composite non-food commodity consumed by household
$\beta 1$	Expenditure share for composite seafood commodity consumed by household
$\mu 1$	Elasticity of substitution between composite seafood commodity vs. non-seafood food commodity consumed by household

$\beta2_{nfc}$	Expenditure share for non-food commodity *nfc* consumed by household
$\mu2$	Elasticity of substitution among non-food commodities consumed by household
$\beta3$	Expenditure share for composite raw fish commodity consumed by household
$\mu3$	Elasticity of substitution between composite raw fish commodity and processed seafood commodity consumed by household
$\beta4_{rf}$	Expenditure share for raw fish commodity *rf* consumed by household
$\mu4$	Elasticity of substitution among raw fish commodities consumed by household

Budget of Household

wleakr	Labor income leakage rate
rleakr	Capital income leakage rate
esrate	Enterprise savings rate
MPS	Marginal propensity to save
trrg	Regional income tax rate for household
trng	National income tax rate for household

Budgets of Governments

rgibt	Regional gov't. indirect business tax share
ngibt	National gov't. indirect business tax share
$rgles_c$	Regional gov't. demand commodity share
$ngles_c$	National gov't demand commodity share
nrrat	Ratio of national gov't transfer to regional gov't to national gov't revenue

Capital and Investment

ktrng	National tax rate on capital
ktrrg	Regional tax rate on capital
$invrat_c$	investment ratio for commodity *c*

Factor market

R	Return to capital in the base year

Logistic growth function

γ	Intrinsic growth rate
KC	Carrying capacity

B.2 Data and calibration

This section describes the procedures used to construct the Busan social accounting matrix (SAM, Appendix A, Table A.2), the data set used to develop the Busan CGE model, and how the model is parameterized and calibrated.

This study started from 16-region, 33-sector multi-regional input-output (MRIO) data for 2015 [Bank of Korea (BOK)] to develop the Busan SAM. Busan is one of the 16 regions. This MRIO dataset provides for each of the 16 regions the information on (i) inter-industry transactions within the region, (ii) employee compensation, (iii) operations surplus, (iv) indirect business taxes, (v) final demand (consumer demand, investment demand, government demand,

and both domestic and foreign exports) for commodities, (vi) the transactions between each of the industries in the region and each of the industries in the other regions, and (v) imports from, and exports to, other domestic regions and foreign countries. This study aggregated all 15 non-Busan regions into the rest of the country (ROC). Next, the trade flows between Busan and ROC and those between Busan and the rest of the world (ROW) are separately estimated based on the MRIO data.

There are two governments in the model, the national government and the regional government. The regional government is the combination of the provincial government (i.e., the Busan government) and all the lower-level governments. Information on regional government expenditures is from the Local Finance Integrated Open System (LFIOS 2022). To obtain the national government demand, the regional government expenditures are subtracted from the total government demand in the BOK IO data above. The national government revenues (taxes) and expenditures on items other than goods and services purchased by the government (e.g., transfer payments) are estimated using the National Tax Service Annual Report (NTSAR, National Tax Service of Korea 2016, for 2015 data). Regional government revenue and expenditure information are from the Annual Local Tax Statistics Report (ALTSR, Ministry of the Interior 2016, for 2015 data) and LFIOS (2022), respectively.

The 33-sector MRIO dataset has highly aggregated sectors and does not separately identify the fish-producing and fish-processing industries. In the dataset, fish production is included in the Agriculture, Forestry, and Seafood Production sector, and seafood processing is included in the Food and Drinking sector. Using data from KOSIS (2022), fish production is separated from the Agriculture, Forestry, and Seafood Production sector. Then, this fish production sector is further disaggregated into mackerel production, non-mackerel production, and aquaculture, using data from KOSIS (2022). Next, seafood processing is separated from the Food and Drinking sector. Finally, the last two industries (Other Service and Other) in the MRIO dataset are combined into a single sector. Thus, the number of industries in the final SAM is 36 (Appendix A, Table A.1). Data on household tax payments to the national and regional governments are from the Household Income and Expenditure Survey (HIES, Statistics of Korea 2016) for 2015, NTSAR, and ALTSR. Using the data thus estimated as above, the Busan SAM is constructed and is available upon request. When balancing the SAM, the elements in the exogenous accounts are adjusted until the column sums equal the row sums.[8]

Previous studies estimated the stock elasticity values. For instance, Finnoff et al. (2007) estimate the stock elasticity to be 0.21 for the Alaska pollock fishery. Some CGE studies do not estimate the elasticity econometrically but assume or estimate it based on previous studies. For example, Manning et al. (2018) assume an elasticity value of 0.4 for an artisanal fishery in Honduras. Based on previous studies, Gilliland et al. (2022) choose a stock elasticity of 0.645 for a local area's fishery in the Philippines (El Nido on the island of Palawan). The present study simply assumes that the stock elasticities for the two fisheries are 0.4, as in Manning et al. (2018), which is close to the average of the other two estimates (Finnoff et al. 2007 and Gilliland et al. 2022).

[8] This study uses this method to balance the SAM rather than using bi-proportional adjustment techniques (e.g., RAS technique) in order to keep the original parameter values (e.g., production functions and other key behavioral and endogenous share parameters) implied in the SAM, but allow the peripheral elements in the exogenous accounts to be adjusted when necessary to balance row and column totals.

Further, this study assumes that the fish harvest function is a constant returns to scale function, implying that the effort elasticity is set to 0.6. The catchability parameter (*d*) is calibrated given the base-year level of harvest, the two elasticities (stock and effort elasticities), and the base-year levels of effort and biomass. The calibrated values of the catchability parameter are 1.379 (mackerel sector) and 0.002 (non-mackerel sector), respectively.

The base-year quantity of a factor of production (labor or capital) in an industry is calibrated such that it equals its base-year factor income divided, for convenience, by 1 million KRW. Note that the base-year factor income here includes only that portion of the total factor income which represents its opportunity cost (the market price of the factor). For the fishing industry, this factor income excludes the resource rent.[9] Calibrating the quantity of a factor for a fishing industry in this manner means that the market price of the factor is 1 million KRW in the base year.

The base-year level of effort is calibrated simply as the sum of labor, capital, and intermediate input use. The shift parameter is calibrated given the base-year level of effort, the elasticity of substitution, and the share parameter in the effort function (Equation (5) in the text). This yields the unit cost of effort (*C*) in Equation (8) in the text which equals 1 million KRW in the base year, meaning that the unit of effort is calibrated such that one unit of effort costs 1 million KRW. Calibration of parameters for non-fishing sectors is carried out similarly.

The elasticity of substitution in the effort function (which aggregates *LAK* and *INT* in the second stage, Figure B.3.1) is initially set to 0.61 for the two fish harvesting sectors. The elasticity of substitution in the CES value-added composite function (third stage, Figure B.3.1, function not shown in the text) is set to 0.61 for the two fish harvesting sectors, following de Melo and Tarr (1992). The shift parameter is calibrated given the base-year level of the *LAK*, the elasticity of substitution, and the share parameter in the CES value-added function. This yields the unit cost of *LAK* that equals 1 million KRW in the base year, meaning that the unit of *LAK* is calibrated such that one unit of *LAK* costs 1 million KRW. The elasticity of substitution in the composite intermediate input function (*INT*, a CES function, third stage, Figure B.3.1) is set at 0.61. Calibration of the shift parameter in this CES composite intermediate input function is conducted in a similar way as in the *LAK* function above.

The elasticity of substitution among non-food commodities (second stage, Figure B.3.2) is set to the average value (1.125) of the elasticities for low- and high-income households from Shoven and Whalley (1984). It is assumed that the elasticity of substitution between food and non-food commodities (first stage) is much smaller than this average (1.125) and is set at 0.5. Since seafood and other food are likely more substitutable for each other than the non-food commodities are, this study sets the elasticity of substitution between seafood and other food at a higher value of 1.5. The elasticity of substitution between the composite raw fish commodity and processed fish (third stage) is set at a higher value (2.0) than this value (1.5) because it is likely that the substitutions between these two commodities are much easier than between seafood and the non-seafood food commodity. Finally, the elasticity of substitution among the three raw fish

[9] Since both the mackerel and non-mackerel fisheries are currently under a regulated open access regime, it is assumed that some positive rent exists in these fisheries in the base year.

commodities from the three different fish-producing industries is set at a much higher value of 5 to reflect the likelihood of easier substitution.

The elasticities of substitution in the nested Armington function (Figure B.3.3) for the seafood commodities (raw fish and processed fish) in the second-stage optimization are set at 2.41 and 3.35, respectively, based on Donnelly et al. (2004), Zhang and Verikios (2006), and ABPmer et al. (2018). The elasticity values for all the other commodities in the second stage are based on the central estimates in de Melo and Tarr (1992, p. 231). In the third stage, the elasticity values for all commodities are set at a high value of 10 because it is likely that the substitution occurs much more easily between the commodities produced in the study region and those from ROC than between the regionally-produced commodities and those imported from foreign countries.

In the literature, there are only a few studies that estimate the elasticity of substitution between a commodity produced in a region within a country and the version imported from elsewhere in the country. Bilgic et al. (2002) estimate that the Armington elasticities for inter-regional trade within the US range from 0.45 to 2.80, depending on the commodities, failing to prove the hypothesis that international trade elasticities are lower bounds for regional trade elasticities. In contrast, Zofio et al. (2020) confirm the hypothesis by reporting that the Armington elasticities for inter-regional trade range from -5.1 to 49.4 when they are estimated using trade data for individual sectors while they range from 1.84 to 124.2 when estimated using the pooled data.

The elasticities of transformation in the second stage (Figure B.3.4) in the CET function are from de Melo and Tarr (1992) while the elasticities for all commodities in the third stage are set at 10 for a reason similar to the aforementioned one. The shift parameters in the two CES Armington functions and the two CET functions are calibrated in a standard way. That is, the shift parameters in these functions are calibrated given the elasticity values and the base-year levels of the variables in the functions. This study sets the import supply and export demand elasticities for domestic trade at 10 in the baseline simulation. For comparison, in de Melo and Tarr (1992, p. 103), the export demand elasticities are set at 3, 4, or infinity while the import supply elasticities are set at 4, 5, and infinity, depending on the commodities, for a national (US) CGE model.

To calibrate the parameters in the logistic growth function (Equation (21) in the text), this study uses the harvest data from KOSIS (2022) and bioeconomic parameters in Hong and Kim (2021). Using the Bayesian state-space (BSS) method (Froese et al., 2017), Hong and Kim (2021) estimated for the Korean mackerel fishery the intrinsic growth rate of 0.42, the biomass of 442,660 tons, and the carrying capacity of 1,419,923 tons, resulting in the initial ratio of biomass to carrying capacity of 0.312. This study used these parameters to calibrate the logistic growth function in the present study. Specifically, given the growth rate, the Busan's mackerel harvest (KOSIS, 2022), and the ratio of the biomass to the carrying capacity above (0.312), this study calibrates the biomass level and the carrying capacity for Busan's mackerel fishery, assuming that the bioeconomic system is on a steady-state path in the base year. This method of calibration is similar to Manning et al. (2018) and Gilliland et al. (2022), where the parameters are calibrated assuming that the biomass-to-carrying capacity ratio is fixed and the bioeconomic system is in a steady state in the base year.

The discount rate is set at 4.5% (Ministry of Economy and Finance 2018) in all the simulation except for Status Quo simulation. For a list of the values of the parameters (elasticities) used in this study and their sources, see Tables B.2.1 and B.2.2 for the baseline simulations and Table B.2.3 below for sensitivity analyses.

Table B.2.1 Description of trade-related functions and elasticities for Busan's mackerel fishery (Baseline simulations)

Description	Elasticity
Import demand	
Busan's demand for imports from the rest of the country	10.0
Busan's demand for imports from foreign countries	2.41
Import supply	
Rest of the country's supply of imports to Busan	10.0
Foreign countries' supply of imports to Busan	Infinity
Export demand	
The rest of the country's demand for exports from Busan	10.0
Foreign countries' demand for exports from Busan	Infinity
Export supply	
Busan's supply of exports to the rest of the country	10.0
Busan's supply of exports to foreign countries	3.9

Table B.2.2 Parameter values used in the baseline simulations

Elasticities and Parameters	Value
Elasticity of Effort in Harvest Function [a]	
Mackerel fishing	0.6
Non-mackerel fishing	0.6
Elasticity of Stock in Harvest Function [a]	
Mackerel fishing	0.4
Non-mackerel fishing	0.4
Elasticity of Substitution in Fish Production	
1st stage (effort vs. biomass)	1.0
2nd stage (value-added vs. composite intermediate input)	0.61
3rd stage (labor vs. capital) [b]	0.61
3rd stage (among intermediate inputs)	0.61
Elasticity of Substitution in Non-fish Production (stages 1 and 2) [b]	
Agriculture and Forestry, Aquaculture, and Mining	0.61
Seafood processing	0.79
All the other industries	0.80
Elasticity of Substitution in Consumption [c]	
1st stage (food vs non-food)	0.5
2nd stage (seafood vs. other food)	1.5
2nd stage (among non-food commodities)	1.125
3rd stage (raw fish vs. processed fish)	2.0
4th stage (among raw fishes)	5.0
Elasticity of Substitution between Imports and Local Goods [d]	
2nd stage (foreign imports vs. domestically supplied goods)	
Raw fish (mackerel fishing, non-mackerel fishing, and aquaculture)	2.41
Agriculture and Mining	1.42
Seafood processing	3.35
Construction	3.15
All manufacturing commodities except seafood processing	3.55
All the other commodities	2.00
3rd stage (all commodities)	10
Elasticity of Transformation in Production: Regional Goods and Exports [e]	
2nd stage	
Agriculture, Mackerel fishing, Non-mackerel fishing, Aquaculture, and Mining	3.9
All manufacturing commodities and Construction	2.9
All the other commodities	0.7
3rd stage (all commodities)	10
Import supply elasticity for imports from the rest of the country	10
Import supply elasticity for imports from foreign countries	Infinity
Export demand elasticity for exports to the rest of the country	10
Export demand elasticity for exports to foreign countries	Infinity

Source:
a Authors' assumption based on previous estimates
b The elasticity values are based on de Melo and Tarr (1992, p. 232).

c The average value of the elasticities for low- and high-income households from Shoven and Whalley (1984) is 1.125. The present study uses this value for the elasticity of substitution among non-food commodities. It is assumed that the elasticity of substitution between food and non-food (1st stage) is less than this average, and is set at 0.5. It is also assumed that the elasticity values for the other stages are higher than the elasticity of substitution among the non-food commodities (1.125). As substitutability among seafood commodities becomes higher moving down the utility tree from stage three, the present study sets a higher value. For example, the elasticity of substitution among the three different raw fish products is set at 5.

d The elasticity value for raw fish (2.41) in the 2nd stage in the Armington function is set at the average of the estimates from ABPmer et al. (2018), GTAP Model, Donnelly et al. (2004), and Zhang and Verikios (2006). The elasticity value for processed fish (3.35) is based on Donnelly et al. (2004). The elasticity values for all the other commodities in the 2nd stage are based on de Melo and Tarr (1992, p. 231). In the 3rd stage, the elasticity values for all commodities are set at 10.

e The elasticity values in the 2nd stage are based on de Melo and Tarr (1992, p. 233). The value in the 3rd stage is set at 10.

Table B.2.3 Parameter values or assumptions used for sensitivity analyses

Sensitivity analysis 1 Openness of economy					
Baseline	Highly closed economy	Intermediate case 1	Intermediate case 2	Intermediate case 3	Highly open economy
Perfectly mobile factors. Moderately elastic trade	Closed factor markets. Highly inelastic trade	Closed factor markets. Moderately elastic trade	Total capital stock is fixed. Labor is perfectly mobile. Moderately elastic trade.	Total labor stock is fixed. Capital is perfectly mobile. Moderately elastic trade.	Perfectly mobile factors. Perfectly elastic trade. PE version.

Sensitivity analysis 2 Stock elasticity		
low	baseline	High
0.20	0.40	0.60

Sensitivity analysis 3 Initial ratio of biomass to carrying capacity		
low	baseline	High
0.156	0.312	0.468

Sensitivity analysis 4 Elasticity of substitution in Armington function (2^{nd} stage) for Mackerel		
Low	Baseline	High
0.482	2.41	12.05

Sensitivity analysis 5 Intrinsic growth rate		
Low	Baseline	High
0.27	0.42	0.64

Sensitivity analysis 6 Discount rate		
Low	Baseline	High
0.0225	0.045	0.0675

B.3 Nested functions

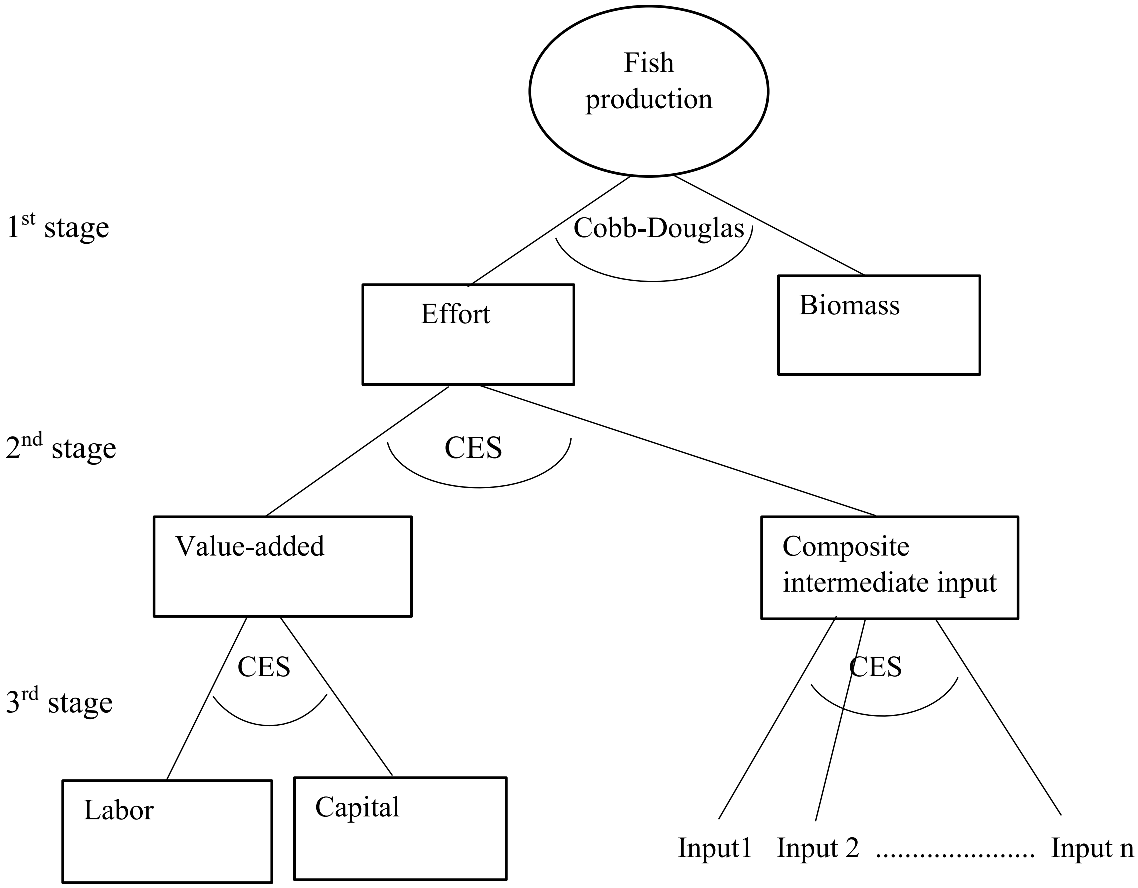

Figure B.3.1 Nested fish production function

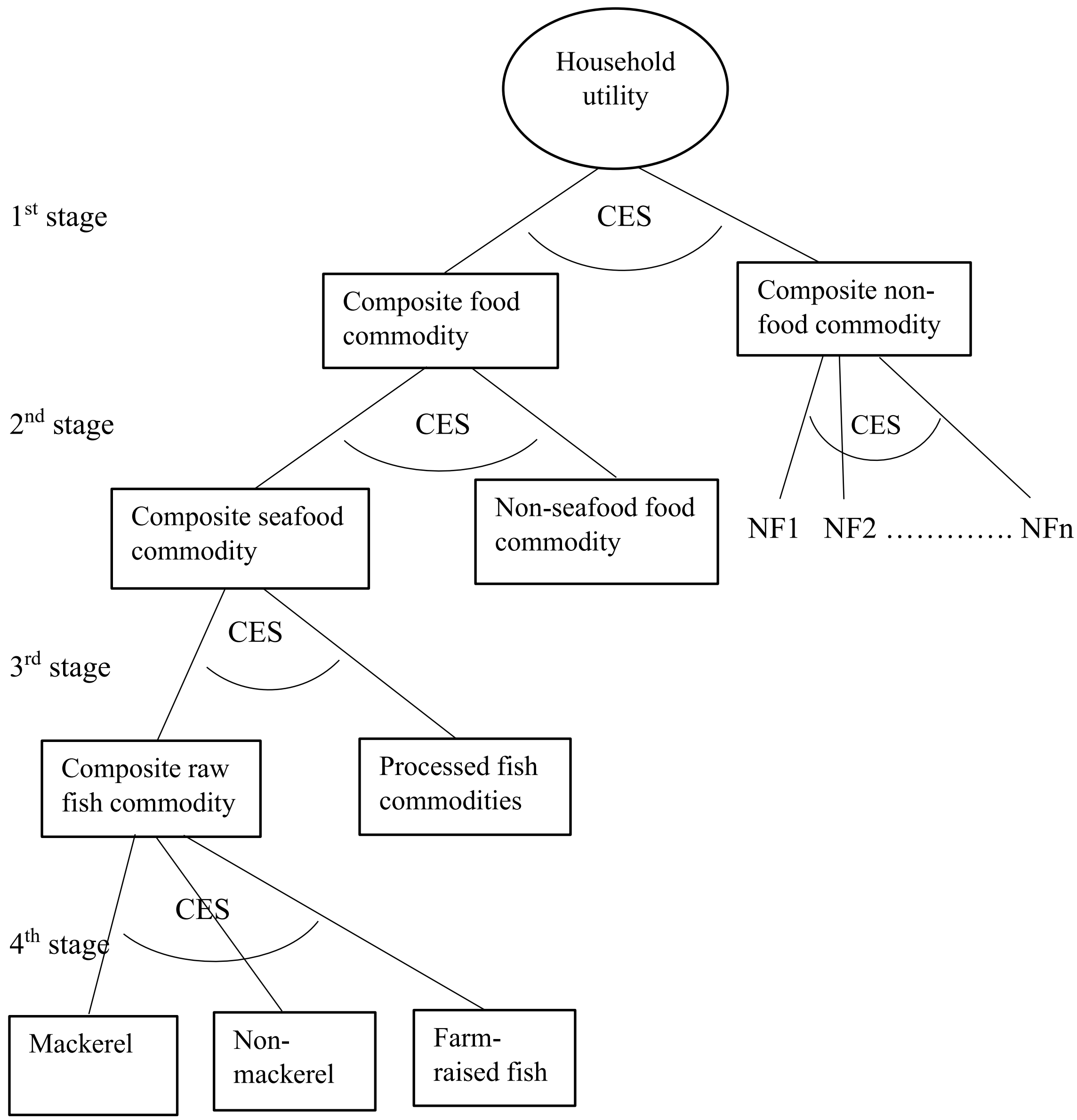

Figure B.3.2 Nested utility function

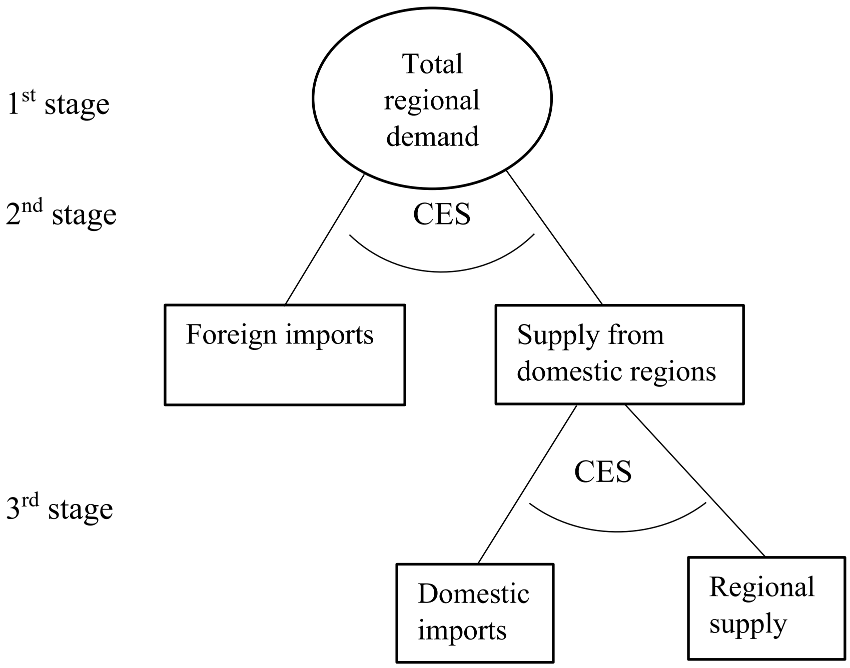

Figure B.3.3 Nested Armington function

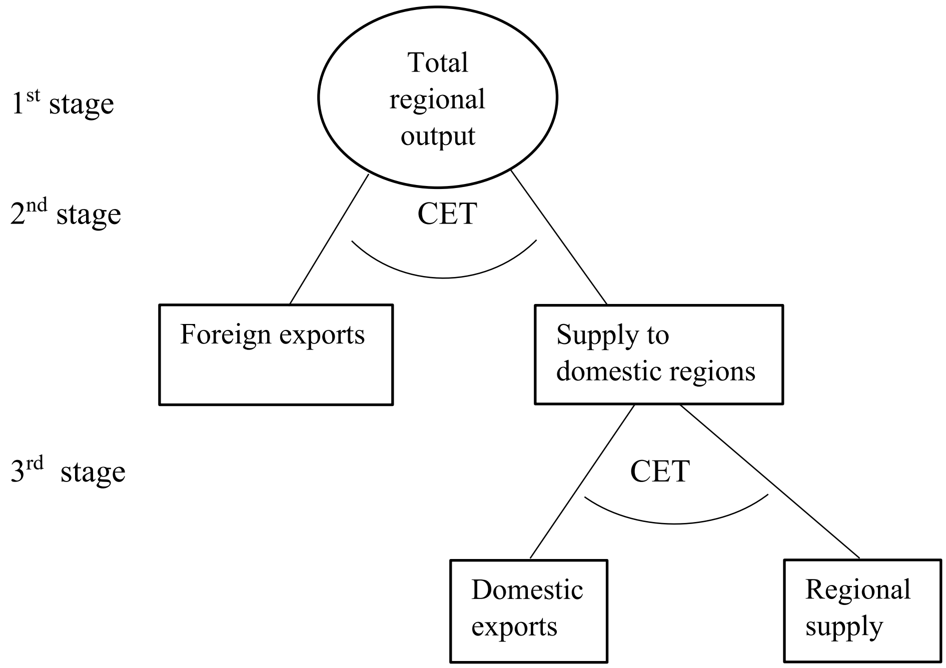

Figure B.3.4 Nested CET function

Appendix C Additional results

Table C.1 Results from sensitivity analyses for Armington elasticity, intrinsic growth rate, and discount rate under MEY (MEY1, MEY11-MEY16).

	MEY1 Baseline simulation	MEY11 Low intrinsic growth rate	MEY12 High intrinsic growth rate	MEY13 Low Armington elasticity	MEY14 High Armington elasticity	MEY15 Low discount rate	MEY16 High discount rate
Effects on fishing sector (% of pre-policy level, steady state)							
Ratio of stock to carrying capacity	0.753	0.750	0.756	0.758	0.741	0.757	0.750
Stock	141.6	140.6	142.3	143.1	137.5	142.7	140.7
Harvest	-13.4	-12.6	-13.9	-14.5	-10.4	-14.2	-12.7
Fish price	2.1	2.0	2.2	2.5	1.1	2.2	2.0
Rent	358.0	357.8	358.1	360.2	352.5	358.2	357.8
Effort	-56.3	-55.5	-56.8	-57.4	-53.3	-57.1	-55.6
Effort price	-0.0020	-0.0020	-0.0020	-0.0020	-0.0020	-0.0020	-0.0020
Aggregate change in non-fishing sectors over time							
Total non-fishing output (% of pre-policy level)	-0.014	-0.018	-0.011	-0.017	-0.006	-0.015	-0.013
Total value-added in non-fishing sectors (billion KRW, discounted)	-225.7	-281.8	-185.7	-261.2	-131.9	-272.6	-193.1
Aggregate welfare change over time							
In billion KRW, discounted	-385.6	-515.0	-292.9	-451.6	-205.3	-448.6	-340.3
As % of pre-policy level of household expenditure	-0.043	-0.058	-0.033	-0.051	-0.023	-0.038	-0.049

Table C.2 Results from sensitivity analyses for Armington elasticities, intrinsic growth rate, and discount rate under MSY (MSY1, MSY11-MSY16).

	MSY1 Baseline simulation	MSY11 Low intrinsic growth rate	MSY12 High intrinsic growth rate	MSY13 Low Armington elasticity	MSY14 High Armington elasticity	MSY15 Low discount rate	MSY16 High discount rate
Effects on fishing sector (% of pre-policy level, steady state)							
Ratio of stock to carrying capacity	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Stock	60.4	60.4	60.4	60.4	60.4	60.4	60.4
Harvest	16.5	16.5	16.5	16.5	16.5	16.5	16.5
Fish price	-2.0	-2.0	-2.0	-2.2	-1.5	-2.0	-2.0
Rent	179.3	179.3	179.3	177.2	185.3	179.3	179.3
Effort	-5.8	-5.8	-5.8	-5.8	-5.8	-5.8	-5.8
Effort price	-0.0002	-0.0002	-0.0002	-0.0003	-0.0001	-0.0002	-0.0002
Aggregate change in non-fishing sectors over time							
Total non-fishing output (% of pre-policy level)	0.006	0.001	0.010	0.006	0.008	0.006	0.006
Total value-added in non-fishing sectors (billion KRW, discounted)	-1.3	-87.0	59.7	-12.3	38.0	48.1	-32.7
Aggregate welfare change over time							
In billion KRW, discounted	98.9	-83.7	226.9	87.5	154.5	237.9	9.8
As % of pre-policy level of household expenditure	0.011	-0.009	0.026	0.010	0.017	0.020	0.001

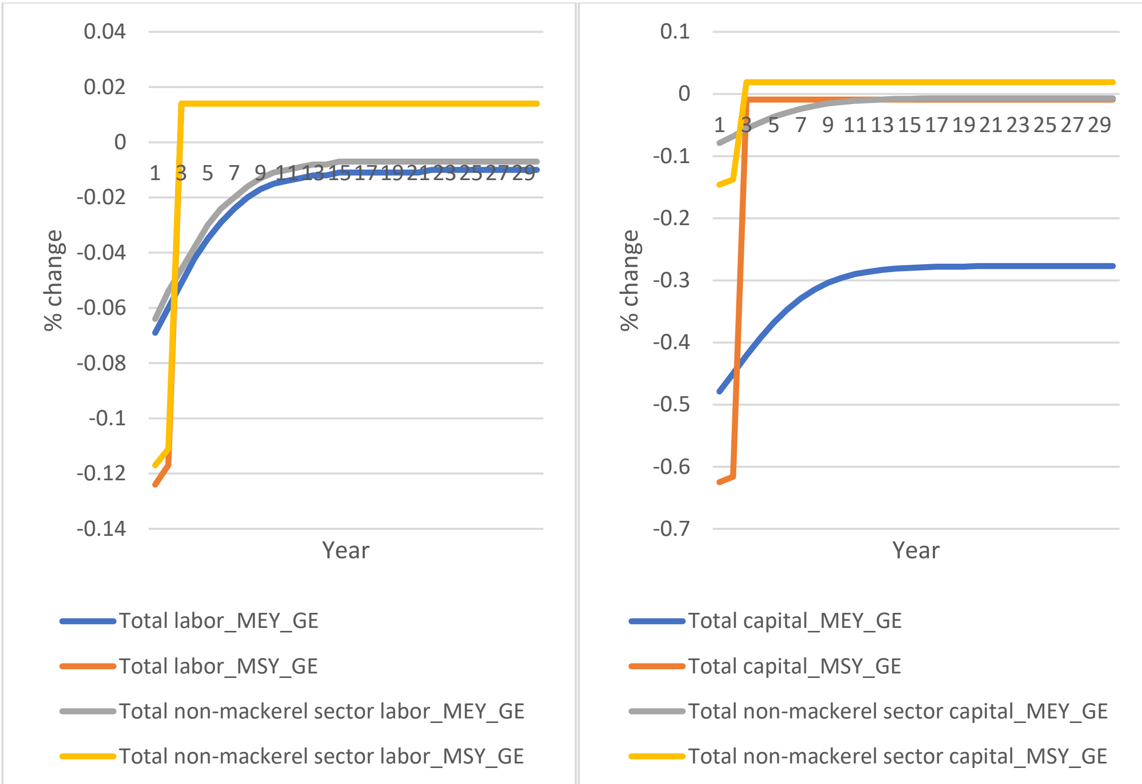

Figure C.1 Percentage changes in total labor stock and total non-mackerel sector labor for MEY and MSY (left) and in total capital stock and total non-mackerel sector capital for MEY and MSY (right). Trajectories labeled MEY_GE and MSY_GE represent GE-based MEY (MEY1) and GE-based MSY (MSY1), respectively.