Does rationalization improve economy-wide welfare? A general equilibrium analysis of a regional fishery in a developed country

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Abstract

This study uses a bioeconomic regional computable general equilibrium (CGE) model to assess the economic and welfare effects on a sub-national region of transitioning from regulated open access to rationalization for a mackerel fishery in a region (Busan), Korea. Results from the baseline simulation demonstrate that the resource rent from the fishery increases, but that the aggregate and per capita welfares in the region can deteriorate due to an out-migration of the factors of production. However, sensitivity analyses reveal that the sign and size of the aggregate and per capita welfare changes depend on, among other things, (i) regional factor mobility, (ii) the ratio of the initial level of biomass to the carrying capacity, and (iii) the magnitude of the rationalization-induced enhancement in the fishing efficiency.

1. Introduction

Traditionally, Korean fisheries had been managed under input controls such as license and effort limitations. Due to the problems of such a management system (e.g., depletion of fishery resources), the Korean government instituted a total allowable catch (TAC) system for its fisheries. In 1999, the government introduced the first TAC for four species (chub mackerel, jack mackerel, sardine, and red snow crab). Since then, it has expanded the number of species governed by the TAC system, to a total of 15 species as of 2022. The TAC system has solved some of the problems of the traditional system but has its own weaknesses, such as race to fish and rent dissipation.

The problems of the TAC system prompted the government to consider rationalizing fisheries including Busan's[1] mackerel fishery using rights-based management. This study investigates the economic and welfare effects of the rationalization of Busan's mackerel fishery using a computable general equilibrium (CGE) model. In doing so, we take the perspective of the regional (not national) policymakers (and fishery managers) who are concerned with regional welfare, focusing on the effects occurring in the region (Busan) where the policy (rationalization) is implemented. Fishery rationalization in this study is defined as granting a limited number of individual fishermen exclusive and transferable rights to a given share of the TAC [i.e., individual transferable quotas (ITQs)].[2]

Chub mackerel (*Scomber japonicus*) (hereafter, 'mackerel') live in warm or tropical waters including offshore and coastal waters of Korea [National Institute of Fisheries Science (NIFS), 2021]. Mackerel is a major species caught in Korean wild fisheries and, along with anchovy and squid, a Korean favorite (Kim, 2017). In 2020, mackerel production was 77,401 tons or about 11% of total fish production from capture fisheries. In the same year, the ex-vessel value of mackerel production was worth about 163,600 million Korean Won (KRW), or $138.6 million.[3] This value was the fourth largest total ex-vessel value, following those of hairtail, anchovy, and yellow croaker harvests, and accounted for about 7% of total ex-vessel revenues from capture fisheries [Korean Statistical Information Service (KOSIS), 2021]. A large fraction (85.8%, 66,444 tons) of the total mackerel harvest was caught by large purse seine, followed by set nets (3.4% or 2,644 tons), small purse seine (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). Busan is where the

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[1] Population in Busan in 2022 was 3,295,760 which was about 6.0% of total republic of Korea's (ROK's) population of 51,692,273. The regional GDP in 2021 was 97.7 trillion KRW (85.4 billion US$, https://data.worldbank.org/indicator/PA.NUS.FCRF?end=2021&locations=KR&start=1995, accessed July 27, 2023) which was about 4.7% of ROK's total GDP of 2,074.2 trillion KRW (1.8 trillion US$) (KOSIS 2023).

[2] The implicit assumption here is that the regulators can *ex ante* determine which units of labor and capital will remain in the fishery following rationalization.

[3] This value 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.

majority of the mackerel caught in Korean waters is landed. In 2021, 83% of the total mackerel catch from Korean waters came from Busan.

The extant literature on fisheries rationalization has largely relied on a partial equilibrium approach, which is limited in that it focuses on the fishing sector and ignores the effects generated due to the interactions between the fishing and non-fishing sectors. When the economy-wide effects of any fishery policies need to be estimated, general equilibrium models are more appropriate than partial equilibrium models. Carbone et al. (2022) discuss when the general equilibrium approach should be adopted against the partial equilibrium approach when analyzing the effects of environmental and resource management issues.

Only a few studies utilized an empirical general equilibrium framework to overcome the weakness of the partial equilibrium approach (Apriesnig 2017, Gilliland et al. 2022, Seung 2024). This study uses a CGE model that enables the investigation of the effects of rationalization transpiring not only in the rationalized sector but also in other sectors linked to the rationalized sector. While some previous CGE studies (Apriesnig 2017, Seung 2024) used a static model, which does not consider the temporal changes in the biomass due to rationalization, the present study considers population dynamics as in Gilliland et al. (2022).

However, our study departs from Gilliland et al. (2022) in several ways. First, the study region in our study is a large region in a developed country where the regional factor markets are highly open to the outside of the regional economy so that factors discharged from the rationalized fishery exit the region. In contrast, the study region in Gilliland et al. (2022) is a small isolated area in a developing country where inter-regional factor mobility is rather limited. Second, the mackerel fishery in Busan has been relatively more efficiently managed, which is evidenced by a relatively high ratio of biomass to carrying capacity (44%) than most fisheries in developing countries [e.g., 20% in Manning et al. (2016) and 36% in Gilliland et al. (2022)]. Third, while Gilliland et al. (2022) rely on a period-by-period optimization approach where decisions on optimal harvest levels are myopic, the optimal harvests in our study are determined within a dynamic optimization framework.

Therefore, the contribution of the present study is two-fold. First, this study examines the economic and welfare effects of rationalization of a local fishery that has been managed relatively well with a relatively high level of fish stock on a large sub-national region characterized by highly mobile factors of production between the study region and other regions. Second, unlike previous studies of fishery rationalization where either decisions on optimal harvest levels are myopic or a partial equilibrium approach is used, the present study adopts a forward-looking modeling framework where the CGE model is embedded within a dynamic optimization problem, as in, for example, Babiker et al. (2009) and Hess et al. (2019). For fisheries, embedding the CGE model within a dynamic optimization problem is important because when the optimal harvest level is determined in each period, the present and future prices of the primary factors of production and intermediate inputs should be taken into account, and these prices are determined by the economy-wide supply and demand within the CGE model. Our study elucidates that, contrary to the findings from previous studies (Apriesnig 2017, Gilliland et al. 2022), the aggregate regional welfare can deteriorate under these circumstances although the resource rent from the rationalized fishery increases.

The remainder of this paper is organized as follows. The next section reviews previous studies on the effects of rationalization, including partial equilibrium and both theoretical and empirical general equilibrium (GE) studies. Section 3 provides an overview of the Busan bioeconomic CGE model, Section 4 outlines the data used and parameter calibration procedures, Section 5 delineates the baseline simulation[4] and sensitivity analyses conducted in this study, and Section 6 presents and discusses the results, including those from several sensitivity analyses. The final section concludes.

2. Previous studies

2.1 Studies on the economy-wide effects of fishery-related policies

Several studies used an economy-wide model to investigate the economic effects on a local area of fishery-related policies although they did not explicitly consider rationalization of fisheries. For example, Lindsay et al. (2020) used a local general equilibrium model to assess the economic and environmental impacts of provisions of fishing and agricultural capital accounting for linkages between households, business sectors, markets, and local fish stocks. Manning et al. (2014) accounted for the economic linkages between resource exploitation and other sectors and market structures when analyzing how market structure impacts fishery exploitation for Northern Honduran fishing communities. Seung et al. (2021) investigated the community-level economic impacts of the reduction in Pacific cod harvest in the Gulf of Alaska arising due to climate change using a 10-region social accounting matrix model.

2.2 Theoretical studies of privatization

Earlier theoretical analyses of the effects of rationalization include those of Weitzman (1974) and Samuelson (1974). These studies show, in a simple general equilibrium (GE) setting, that the wage rate will decrease when a natural resource is privatized. For fisheries, this finding implies that labor would be better off in an open-access fishery than in a rationalized fishery. Several studies have extended the earlier research. For example, Anderson and Hill (1983) showed that under certain institutional arrangements, society

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[4] There are two sequences of solutions in our model. Solving the model without rationalization yields a sequence of benchmark solutions (status quo or open access solutions). Solving the model with rationalization produces a sequence of counterfactual solutions (rationalized fishery solutions). These two sequences of solutions constitute the "baseline simulation."

will not become better off with privatized resources than under free access to resources. By contrast, De Meza and Gould (1987) demonstrated that labor may be better off under privatization than under an open-access regime if other variable inputs are allowed in the model. None of these studies considered the role of capital before Congar and Hotte (2021), who explicitly took into account capital as another variable input and demonstrated that labor can be better off with privatized resources, depending on relative factor intensities in the resources and manufacturing sectors.

2.3 Empirical studies on fishery rationalization study: partial equilibrium analyses

Several studies empirically examined the effects of fishery rationalization. Most of them found that the shift from regulated open access (Homans and Wilen 1997) to rationalization will make fisheries more efficient in generating or increasing resource rent. For instance, Dupont (1990) examined the British Columbia salmon fishery and found that more efficient regulations could create a resource rent equal to 42 percent of the total fishery revenue. Asche et al. (2009) found that, on average, the potential rent from introducing individual vessel quotas to Norwegian trawl fisheries catching cod is approximately two-thirds of the potential fishing vessel revenue. More recently, Abbott et al. (2010) explored the effects of ITQs for the Bering Sea and Aleutian Islands (BSAI) crab fisheries and found that the introduction of ITQs resulted in a decrease in the number of crew members employed in crab fisheries, but an increase in their average remuneration. These studies (e.g., Dupont 1990; Asche et al. 2009; Abbott et al. 2010) offer valuable insights. However, they relied on a partial equilibrium analysis that ignores the relationship between the fishing and non-fishing sectors and did not account for the role of endogenous prices in determining the general equilibrium effects of rationalization.

2.4 Empirical studies on fishery rationalization: CGE studies

Only a few studies used a CGE model to assess the effects of fishery rationalization.[5] For instance, Apriesnig (2017) simulated the shift from an open-access fishery to an ITQ system for Lake Erie yellow perch fishery, using a regional CGE model. Gilliland et al. (2022) investigated the rationalization for a fishing community in the western Philippines using a CGE model. More recently, exploring the rationalization impacts of the Gulf of Alaska groundfish trawl fishery within a CGE framework, Seung (2024) focused on how the results will change depending on the different factor mobility assumptions. While two of these studies (Apriesnig 2017; Seung 2024) relied on a static framework, Gilliland et al. (2022) used a dynamic model that considered the temporal changes in biomass from rationalization.

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[5] A number of empirical studies evaluated the effects of rationalization (privatization) of non-fish natural resources. For example, Behrer et al. (2019) investigated the economic effects of privatization of common-property grazing land on the local economy of Palena, Chile, using a local general equilibrium model, and found that wages in the area rise due to the privatization and a switch to tourism.

The present study represents one of only a few studies on fishery rationalization conducted within a CGE framework and builds on and extends them to evaluate its economic and welfare consequences for a region's (Busan's) mackerel fishery in Korea. Gilliland et al. (2022) assessed the effects of a fishery reform for small-scale fisheries in a small area in a developing country (Philippines), characterized by a high level of exploitation and no restrictions. Compared to Gilliland et al. (2022), the present study explores the effects of a large commercial fishery in a large region of a developed country, which is already under some regulations (e.g., license limitations and TAC). Furthermore, compared to the relatively isolated study area in Gilliland et al. (2022), the region in our study is highly open in the sense that the factors of production are highly mobile between Busan and the rest of Korea. Because of these differences, we obtained the result that the aggregate local (regional) welfare can decrease while the previous studies (Apriesnig 2017; Gilliland et al. 2022) reported that the aggregate regional welfare (real income) increases.

3. Busan CGE model

This section describes the structure of the Busan CGE model. Appendix A provides a full list of the model equations (A.1), variables (A.2 – A.4), and parameters (A.5). Note that subscript *t*, denoting period (time), is suppressed throughout the manuscript including Appendix A where the model equations are presented, except when it is needed to show how a variable changes every period, for example, in the objective function that shows the present discounted value of the sum of the stream of the fishermen's profits and in logistic growth function that updates the fish stock every period.

We started from an Alaska CGE model to develop the Busan CGE model. To address the research questions raised in our study, we have added new features to the Busan CGE model, such as the fish growth function, the effort demand function for regulated open-access fishery[6], and a dynamic optimization framework for modeling rationalized fishery. There are three different versions of input-output data from the Bank of Korea – 34 industry version, 83 industry version, and 165 industry version. We started from the 34 industry version to construct the social accounting matrix. The selection of the 34 industry version was made simply because the resulting model would be more manageable compared to the other two versions. The final number of industries, 36, used in the present study results from disaggregating one single fish-producing sector in the original data into three different fish-producing sectors.

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[6] Another example of modeling regulated open access in CGE is Finnoff and Tschirhart (2008) which links a dynamic CGE model with ecological general equilibrium models for Alaska pollock fisheries.

3.1 Production

The Busan CGE model includes 36 industries (sectors) and 36 commodities (Appendix B, Table B.2). These industries include two wild fish harvesting industries, the mackerel harvesting industry (hereafter, mackerel sector) and non-mackerel harvesting industry (non-mackerel 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 mackerel fishery, with the remainder from non-mackerel fishery (KOSIS, 2022). The total ex-vessel value from mackerel fishery was 201,638 million KRW (US $178.3 million,[7] or 28.5% of Busan's total 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).[8] The management of Busan's mackerel fishery is characterized by regulated open access with TAC and license limitations in place.

The production in each fish harvesting sector is characterized by a Cobb-Douglas (CD) harvest function:

$$H = dE^{f}N^{g}, \tag{1}$$

where H is the harvest level[9], d is the shift parameter or catchability parameter, E is fishing effort, N fish biomass, and f and g effort and stock elasticities, respectively. Effort (E) is determined by a constant returns to scale (CRS) and a constant elasticity of substitution (CES) function:

$$E = \psi\left[\alpha L^{\frac{\sigma-1}{\sigma}} + (1-\alpha)\, K^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{(\sigma-1)}}, \tag{2}$$

where ψ is the shift parameter; L and K are labor and capital, respectively; α and (1-α) are labor and capital shares, respectively; and σ is the elasticity of substitution. Intermediate inputs are used in fixed proportions (i.e., Leontief). The unit cost (C) for this effort function is

$$C = \frac{1}{\psi}\left[\alpha^{\sigma}W^{(1-\sigma)} + (1-\alpha)^{\sigma}R^{(1-\sigma)}\right]^{\frac{1}{(1-\sigma)}} \quad , \tag{3}$$

where W and R are the market wage rate and the return to capital, respectively.

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[7] This value is based on the average exchange rate in 2015 of 1,131 KRW for a US dollar. https://data.worldbank.org/indicator/PA.NUS.FCRF?end=2021&locations=KR&start=1995 accessed Oct. 31, 2022.

[8] Korean Statistical Information Service (KOSIS) provides a wide-ranging major domestic and international data (including fishery data) produced by over 120 statistical agencies covering more than 500 subject matters (https://kosis.kr/eng/aboutKosis/Introduction.do)

[9] Harvest in the non-mackerel sector is fixed in our model reflecting the fact that this fishery is constrained by TAC.

In a pure open-access fishery, fishing firms ignore the effects of their actions on other firms, creating an external diseconomy. Under pure open access, the value of the average product of effort is equal to its unit cost in equilibrium (Weitzman 1974; Lindner et al. 1992; Chichilnisky 1993; Congar and Hotte 2021). Thus, as in Congar and Hotte (2021), the equilibrium condition under pure open access is given as:

$$PV \cdot \frac{H}{E} = C \quad \text{or} \quad \frac{PV \cdot H}{E} = C \ , \tag{4}$$

where $\frac{H}{E}$ is the average product of the effort. Equation (4) states that the value of the average effort product is equal to its unit cost in equilibrium (see also Lindner et al. 1992).

In the real world, however, pure open access is rare, and many open-access fisheries are regulated to varying degrees with some form of restriction. Since regulated open access is an intermediate case between pure open access [Equation (4)] where rent is completely dissipated and fully rationalized fishery where rent is maximized, the equilibrium condition for regulated open access can be expressed as:

$$\frac{k \cdot PV \cdot H}{E} = C \ , \quad \text{where } f < k < 1 \tag{5}$$

Here, the larger the k, the closer the fishery is to pure open access.[10] Therefore, k can be called the degree of openness parameter and is calibrated using the base-year ex-vessel revenue and an estimated value of the resource rent (See Appendix C).

Under a rationalized fishery, optimal harvest levels are determined by maximizing the present discounted value of the present and future profits as:

$$\text{Max } OBJ = \sum_t^T \frac{1}{(1+d)^t} \left(PV_t H_t - C_t E_t\right), \tag{6}$$

where d is the discount rate, PV_t is the price of value-added in period t (i.e., the price of one unit of output minus the expenditures on intermediate inputs used to produce that unit, that is, the income that labor and capital earn by producing one unit of output). When solving this problem, we impose the following constraints:

(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 (Equation (11) below.

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[10] This study is the first that uses k to model partial rent dissipation. The larger k (i.e., the closer the fishery to pure open access), the smaller the pre-rationalization rent. When rationalization is implemented, the larger k, the larger the increase in rent caused by the policy (benefits of rationalization).

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

More details on how to solve the model are found in Appendix D.

This study uses Equation (5) when solving the CGE model for the regulated open-access fishery[11] while the objective function in Equation (6) is maximized when solving the model for the rationalized fishery. The baseline simulation below shows that the harvest and effort levels obtained when solving the CGE model using Equation (6) are lower than those from solving the model with Equation (5), and that effort decreases by a much larger percentage than harvest, increasing resource rent, due to the rationalization.

Production in the other industries is determined by a CRS, CES value-added function. The firms in these industries combine value-added and intermediate inputs in fixed ratios to produce their output. Conditional factor demand functions are derived via cost minimization subject to a given level of output (see Appendix A, Section A.1, Production and input demand section for the equations).

3.2 Resource rent

Note that when deriving Equation (4), it is implicitly assumed that an infinite number of fishermen engage in harvesting the non-exclusive resources in pure open-access fisheries, and the rent is completely dissipated. In the real world, however, pure open access is rare, and many open-access fisheries are regulated to varying degrees with some form of restriction.

In the literature, there are two opposing arguments regarding whether rent is fully dissipated in regulated open-access fisheries. Some studies (e.g., McConnell and Norton 1980; Homans and Wilen 1997) argued that rent can be completely dissipated even if a finite number of vessels engage in regulated open-access fishery. This occurs if vessels can expand their harvesting capacity in a fishery where a positive profit exists. In this case, the expansion of capacity has the same effect as free entry to the fishery, driving the resource rent to zero.

Other studies (e.g., Crutchfield 1979; Anderson 1985) argued that fishing vessels can earn positive rents because there are limitations in the extent to which a finite number of vessels can enlarge their fishing capacity. In this case, rent does not disappear completely, and each fisherman may earn some fraction of the resource rent, although the

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[11] One can solve the model for the status quo (regulated open access) in two different ways. It can be solved for each period with updated level of biomass without using Equation (6) (Congar and Hotte 2021; Brooks et al. 1999). Alternatively, it can be solved using Equation (6) with the discount rate set to infinity (Clark 1990).

fisherman does not have exclusive fishing rights (Cheung 1970).[12] This study adopts the second argument, as in Seung (2024), because Busan's mackerel fishery is a regulated open-access fishery with license limitations and TAC, and the base-year data indicate that some resource rent exists even before it is fully rationalized ($f < k < 1$)[13].

Factor income (FY_s) in a fish harvesting sector is then computed as:

$$FY_s = V_s F_s + \theta_s \cdot RENT, \tag{7}$$

where s denotes factors (labor or capital), V_s is the market price of s (wage rate or return to capital), F_s is the amount of factor s used, and θ_s is the share of the total factor income earned by s in the base year. With two primary factors of production in our study, $\theta_L + \theta_K = 1$ where L and K are labor and capital, respectively. By multiplying the resource rent by θ_s, we assume that the rent is distributed to the factors based on the base-year ratios of their incomes to the total factor income.[14]

θ_s is fixed throughout the model. On the other hand, the degree of openness parameter (k) determines how much of the total factor income is rent in the base year (in the regulated open access). Since θ_s is fixed throughout the model, it is independent of k. Once rent is determined by k under regulated open access or determined by maximizing the present value of the sum of the stream of rents over time under rationalization, it is distributed to labor and capital according to θ_s. In our study, rent remains within the region before and after the policy implementation. So when some factors of production in the mackerel sector out-migrate due to rationalization, only the income of the out-migrating factors, which is calculated using their market prices, leak the region. But the rent accrues to the remaining factors in the mackerel sector.

3.3 Household welfare

There are four different types of households in the Busan CGE model, depending on which industry or industries from (to) which households earn income (provide labor and capital). These are mackerel sector households, non-mackerel sector households, seafood processing households, and all other households (i.e., non-seafood-producing households). Mackerel sector households earn income from the mackerel fishing sector. Non-mackerel sector households are similarly defined. Seafood processing households earn income from the seafood processing sector. The final type comprises catch-all households that earn income from the remaining industries.

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[12] See Brooks et al (1999), Campbell and Lindner (1990), and Grainger and Costello (2016) for further discussion of why resource rent could be dissipated or of the factors that affect the magnitude of the rent.

[13] By contrast, Apriesnig (2017) and Gilliland et al. (2022) simulated the rationalization from one polar case (pure open access) to another polar case (a fully rationalized fishery).

[14] This assumption is similar to the assumption in Manning et al. (2016) that the resource value is split between the factors of production according to their relative contributions to production.

All types of households consume all commodities regardless of which industry they earn income from. For example, non-mackerel sector households do not earn income from mackerel production but consume mackerel. Grouping households in this manner has the advantage of distinguishing between the change in the welfare of the stakeholders directly involved in rationalization (crew and vessel owners in the mackerel sector) and that of the stakeholders indirectly related to rationalization (workers and business owners in seafood processing and non-seafood industries).[15]

The CES utility function represents the preferences of all household types. They consume both locally produced goods and those imported from outside their region. Maximizing the utility of household type h (h = 1, 2, 3, and 4) subject to its budget constraint yields the demand function (see Appendix A, Section A.1, Household demand section, Equation (21)). This study uses equivalent variation ($EV_{h,t}$) to measure the welfare change for household h in period t, given by:

$$EV_{h,t} = e\left(\boldsymbol{p}_t^0, U_{h,t}^1\right) - e\left(\boldsymbol{p}_t^0 , U_{h,t}^0\right) , \tag{8}$$

where e denotes the expenditure function, $\boldsymbol{p}_t^0$ is a vector of pre-policy prices of the commodities consumed by households in period t, and $U_{h,t}^1$ and $U_{h,t}^0$ are post- and pre-policy levels of household utility in period t, respectively. The aggregate regional welfare change in period t is given by:

$$EV_t = e(\boldsymbol{p}_t^0, U_t^1) - e(\boldsymbol{p}_t^0 , U_t^0) , \tag{9}$$

where EV and U are now defined for the aggregate household.

However, the welfare change estimated by Equation (9) is based on the assumption that the population size does not change. In some simulations in our study (baseline simulation and sensitivity analysis for factor mobility), the number of residents may change after a policy (fishery rationalization in this study). Therefore, to account for the different population sizes due to labor out-migration, we computed *per capita* welfare change for the aggregate household (Ballard et al. 1985). Thus, the sum of the stream of the present discounted values of *per capita* welfare changes for the aggregate household ($PVWEL$) is calculated as:

$$PVWEL = \sum_t^T \frac{1}{(1+d)^t} \left[\frac{e\left(\boldsymbol{p}_t^0, U_t^1\right)}{POPC_t} - \frac{e\left(\boldsymbol{p}_t^0 , U_t^0\right)}{POPB_t}\right], \tag{10}$$

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[15] To estimate the disposable incomes of the different types of households, we used the value-added (labor and capital incomes) in the industry columns in the social accounting matrix (SAM) net of all taxes. Households defined in this way do not exist in the real world, but were constructed for this study. Classifying households in this manner has an advantage over classifying households by income level (e.g., low, medium, and high income households), in which case it is difficult to separately compute the welfare effects for the stakeholders in the rationalized fishery.

where $POPC_t$ and $POPB_t$ are post- and pre-policy sizes of population, respectively and $\frac{e(\boldsymbol{p}_t^0, U_t^1)}{POPC_t}$ and $\frac{e(\boldsymbol{p}_t^0, U_t^0)}{POPB_t}$ are post- and pre-policy levels of per capita expenditure.[16]

3.4 Imports and exports

Consumers in Busan minimize their expenditure on a composite commodity consisting of a mix of locally produced and imported portions from the rest of the world (ROW), subject to the CES Armington function (Armington 1969, Equation (49) in Appendix A, Section A.1). This yields an import demand function (Equation (50) in Appendix A, Section A.1), which states that the mix of locally produced and imported goods used in the region is determined by the ratio of the price of each locally produced good to the price of its imported counterpart, subject to the substitutability constraint. Similarly, firms in Busan maximize their revenues from the sale of a good to the local market and export market (ROW market), subject to a constant elasticity of transformation (CET) function (Equation (47) in Appendix A, Section A.1). This yields an export supply function (Equation (48) in Appendix A, Section A.1), which states that the mix of output allocated between the local market and the ROW market is determined by the ratio of the export price of each good to its local price, subject to the substitutability constraint. This study adopts a "small-country (region)" assumption that the region's imports and exports of goods (including fish) do not wield a strong power in the ROW market. This means that import supply and export demand are infinitely elastic and that the prices of imports and exports are fixed in the CGE model (See Equations (1) and (2) in Appendix A, Section A.1, Prices section and Exports and imports section).[17]

3.5 Regional factor mobility

In the fisheries economic literature, a few studies investigated the factor leakage issue. For example, Cunningham et al. (2016) found evidence that a catch share program for the New England groundfish fishery caused leakage of effort (capital) from the fishery to adjacent Mid-Atlantic fisheries. Several CGE studies (e.g., Apriesnig 2017; Congar and Hotte 2022) of fishery rationalization assumed that the total stocks of labor and capital available in the study region are fixed. Thus, if they are released from the rationalized fishing industry, they can flow to non-fishing industries within the region.

The present study assumes that labor released from the rationalized fishery may or may not remain in the region. Without any evidence concerning labor mobility in the study

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[16] In calculating per capita expenditures, it is assumed that the labor force participation rate for the study region is fixed so that the ratio of $POPC_t$ to $POPB_t$ in Equation (10) equals the ratio of post- to pre-policy levels of total regional labor stock.

[17] Although Busan's economy is larger than that of the study region in Gilliland et al. (2022), our study region is still a very small region compared to ROW (including foreign countries) in the sense that its imports and exports will not affect their world prices significantly. Thus, it seems reasonable to treat Busan as a small region compared to ROW.

region, this study first assumes that total labor in the region is fixed, and the labor discharged from the rationalized fishery stays and finds employment elsewhere in the region with the market wage rate endogenously determined (baseline simulation) (Appendix A, Section A.1, Equation (52) in Equilibrium conditions section and Model closures section). Later in a sensitivity test, this study relaxes this assumption and assumes alternatively that labor is mobile between the region and the ROW, meaning that the market wage rate is fixed and equalized between the regions. In this case, total labor in the region is endogenously determined.

The assumption that the total capital stock is fixed within the study region in some previous studies may not be realistic for most fisheries because of the uniqueness of fishing capital (Seung 2024). In many cases, fishing capital may not be used in non-fishing industries (due to the non-malleability of fishing capital). 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 non-fishing industry. This assumption may not be realistic for Busan's mackerel fishery because the use of capital in the fishery is likely to change/decrease because of the rationalization.

For most fisheries, including Busan's mackerel fishery, it is likely that if capital is discharged from a fishery due to government policy, it will either be absorbed in the region's non-seafood industries or exit the region. However, fishing capital (vessels) released from the rationalized fishery will not be likely to flow to the other fisheries because these other fisheries are under license limitations, meaning that the owners of released capital cannot enter these other fisheries unless the vessel owners from the released capital replace the existing permit holders in these other fisheries, for example, due to their retirement. Furthermore, the production in these other fishing sectors in the region is fixed in our study because they are under the TAC system, limiting the inflow of fishing capital from the rationalized fishery.

Therefore, this study first assumes (in the baseline simulation) that fishing capital from the rationalized fishery exits the region with the market return to capital fixed and equalized between the study region and the ROW (Appendix A, Section A.1, Equation (53) in Equilibrium conditions section and Model closures section). In this case, the total capital in the region is endogenously determined. Later in this study, a sensitivity analysis is carried out to examine how the results change if it is alternatively assumed that the fishing capital from the rationalized sector can be used in the non-fishing industries within the economy, as in previous studies, meaning that the total capital in the region is fixed and the market return to capital is endogenously determined. For further discussion of other possibilities of factor mobility for rationalized fisheries, see Seung (2024).

3.6 Dynamics

When the harvest level (*HARV*)[18] changes following rationalization, it changes the stock level (*N*). In this study, we assume that stock grows following the logistic growth function:

$$N_{t+1} = N_t + \gamma N_t \left(1 - \frac{N_t}{KC}\right) - HARV_t, \qquad (11)$$

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 via Equation (1).

An increase in the stock level caused by reduced harvest lowers vessels' search costs for some inputs (e.g., fuel) incurred to locate the fish (Wilson 1990; Jensen and Vestergaard 2003). Thus, following Jensen and Vestergaard (2003) and Gilliland et al. (2022), this study assumes that the cost of fuel, one of the most important intermediate inputs used in fishing, declines as the stock level rises.

$$a\_fuel_t = \frac{GFL}{(N_t)^n}, \qquad (12)$$

where a_fuel_t is the input-output coefficient for fuel use in period t. *GFL* is a coefficient determining the relationship between the fuel input coefficient and the biomass and is calibrated such that a_fuel_0 (i.e., the base-year value of *a_fuel*) is reproduced given the base-year level of the stock. *n* is a coefficient that shows how fast the fuel cost decreases as the level of the stock rises. Therefore, an increased stock reduces the search cost, leading to an increase in the price of value-added, contributing to an increase in the resource rent.

3.7 Fishing efficiency

In this study, rationalization improves fishing efficiency through three pathways. First, efficiency may be enhanced through a lower level of effort to catch a given volume of fish. Second, efficiency may be improved through an increase in catchability [*d* in Equation (1)] caused by rationalization. Apriesnig (2017) showed that the magnitude of the effects of an ITQ system varies depending on how much catchability improves owing to the ITQ system. Seung (2024) revealed that the effects of rationalization vary significantly depending on changes in catchability. Third, efficiency can also be enhanced through a decrease in the use of intermediate inputs (e.g., fuel) when the biomass grows because of rationalization, as modeled in Equation (12) above. In addition to carrying out a baseline simulation with all three pathways considered in the model, this

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[18] 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).

study performs sensitivity analyses for the catchability and search cost function parameters (n).

4. Data and calibration

In this section, we describe how we constructed the Busan social accounting matrix (SAM) needed to develop the CGE model. Readers are referred to Appendix C for descriptions of how we parameterized and calibrated the model.

To develop the Busan SAM, this study started with a 16-region (one of which is Busan), 33-sector multi-regional input-output (MRIO) matrix for 2015 from the Bank of Korea (BOK). This MRIO dataset provides information on (i) inter-industry transactions within the region for each of the 16 regions; (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; and (vi) the transactions between each of the industries in this region and each of the industries in the other regions.

All 15 non-Busan regions were integrated into the ROW account, which includes the rest of Korea (ROK) and all foreign countries. Next, the trade flows between Busan and the ROW were estimated based on MRIO data. To estimate total government demand, this study first combined government expenditure with government investment for each commodity in the Busan IO data. The single government sector in the data was then divided into two government sectors: national and regional. Here, the regional government is a combination of the provincial government (i.e., Busan's government) and all lower-level governments (e.g., *Kus* and *Dongs*).

To allocate the total government demand for goods and services between the national and regional governments, this study subtracted from the total government demand the regional government expenditures, which were estimated based on the Local Finance Integrated Open System (LFIOS 2022), to obtain the national government demand. National government revenues (taxes) and expenditures on items other than goods and services purchased by the government (e.g., transfer payments) were 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 taken 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 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 was separated from the Agriculture, Forestry, and Seafood Production sector, and then further disaggregated into mackerel production, non-mackerel production, and aquaculture. To develop the input-output coefficients for the three fish production industries, we used the production and revenue information from the Korean Statistical Information Service (KOSIS 2022) and cost information from the National Federation of Fisheries Cooperatives (NFFC 2022). Seafood processing, too, was separated from the Food and Drinking sector. Finally, the last two industries (other services and others) in the MRIO dataset were combined into a single sector. Thus, the number of industries in the final SAM was 36.

Data on household tax payments to national and regional governments were obtained from the Household Income and Expenditure Survey (HIES, Statistics of Korea 2016) for 2015, NTSAR, and ALTSR. The aggregate household sector in the Busan IO data was divided into four different household sectors (types) depending on the industry from which households receive their factor income. The savings rates and tax rates for the four types of households were assumed to be the same as those for the aggregate household in the original Busan IO data. Using the data as estimated above, the Busan SAM was constructed (Appendix B, Table B.1). When balancing SAM, we adjusted the elements in the exogenous accounts until the column sums equal the row sums.[19]

5. Baseline simulation and sensitivity analyses

5.1 Baseline simulation

We first quantified the effects of rationalization with the baseline values of the parameters (Appendix B, Table B.3). The CGE model was solved with a regulated open-access regime first. This process produced a sequence of benchmark solutions. In our study, the variables in the sequence of the benchmark solutions were computed to be constant over time. This includes the mackerel sector fish harvest (or total desired catch); it is not fixed within the model but is endogenously computed to be constant in the sequence of the benchmark solutions. The model was then solved with rationalization. This process produced a sequence of counterfactual solutions. When solving the model with and without the policy, we assumed that labor is mobile within the region, capital is mobile between the study region and the ROW, the bioeconomic system is in a steady state in the base year, and catchability does not change because of rationalization. We allowed a sufficient number of solution periods, setting the last period at the 100th year beyond the base year. We found that by the 30th year, the economic and ecological system converges to a steady state. These two sequences of solutions constitute the "baseline simulation." The effects of rationalization were calculated by comparing these two sequences.

5.2 Sensitivity analyses

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

This study conducted several sensitivity analyses for the parameters and assumptions used. See Appendix B (Table B.4) for the parameter values used in the sensitivity analyses. There are three broad categories of parameters or assumptions that may influence the effects of rationalization. They are (i) the openness of the regional economy to outside economies, (ii) rationalization-induced improvement in fishing efficiency, and (iii) the parameters in the fish growth function.

5.2.1 Sensitivity analyses for the openness of the regional economy

The rationalization effects may vary depending on how open the regional economy is to outside economies in terms of international and inter-regional trade of commodities and inter-regional factor mobility. First, the effects may hinge on the responsiveness of imports and exports of raw fish to the change in the price of the regionally-produced fish relative to the price of the imported/exported fish. Responsiveness is measured by the elasticity of substitution in the CES Armington function for imports and the elasticity of transformation in the CET function for exports. This study examines the sensitivity of the results to the perturbations in these elasticities. Second, alternative regional factor mobility assumptions may alter the results. In a sensitivity analysis, it was first assumed that both labor and capital stocks available in the region are fixed (i.e., the regional factor markets are closed to their ROW counterparts). Next, it was assumed that both factors are perfectly mobile both inter-sectorally and inter-regionally (i.e., regional factor markets are completely open to their ROW counterparts).

5.2.2 Sensitivity analyses for efficiency improvement

The effects may also change depending on the extent of efficiency improvement induced by rationalization. Efficiency may increase through improvements in catchability. Several previous studies measured changes in fishing efficiency induced by rationalization. For instance, Sigler and Lunsford (2001) estimated the change in catching efficiency caused by the implementation of an individual fishing quota (IFQ) system in 1995 for the Alaska sablefish longline fishery and found that the catch rate increased by 63% owing to IFQ. Fox et al. (2006) measured the productivity increase induced by an ITQ system in an Australian trawl fishery. Their study revealed that, from 1997 to 1998, profits rose by 39% for small vessels and 26% for large vessels, due to the increase in productivity. In the present study, catchability was increased by increments of 10% to 30% to gauge the variability of the effects. The catch efficiency may also be improved by fuel cost savings from increased biomass. Therefore, this study perturbed the search cost function parameter (n) to explore model sensitivity.

5.2.3 Sensitivity analyses for fish growth function

Model results may differ depending on the assumptions regarding the parameters in the logistic growth function. This study first varied the intrinsic growth rate based on Hong and Kim (2021), which estimated the growth rate for Busan's mackerel biomass to be

0.42, with its lower and upper bounds being 0.27 and 0.66, respectively. Here, the growth rate was first lowered from the baseline value (0.42) to 0.27 and then raised to 0.66 to quantify the sensitivity of the effects. Furthermore, the model results may be sensitive to the initial stock level relative to the carrying capacity (Manning et al. 2016). For this sensitivity test, the effects of rationalization were simulated with different ratios of the initial level of biomass to its carrying capacity [N/KC in Equation (11)]. In the baseline simulation, N/KC was set at 0.443. For sensitivity tests, the ratio was lowered by 20% and 40%.

We conducted sensitivity analyses for all the parameters or assumptions in the three categories above. However, we report only the results from the analyses for three parameters/assumptions to which the results are significantly sensitive. These parameters and assumptions are (i) factor mobility, (ii) the ratio of the initial level of stock to its carrying capacity, and (iii) the catchability parameter. Results from the sensitivity analyses for other parameters are available upon request.

6. Results and discussion

The results from the baseline simulation are presented in Table 1 and Figures 1 and 2. In addition, we present the results from the three sensitivity analyses in Tables 2-4 – factor mobility, catchability parameter, and the ratio of biomass to carrying capacity because these three analyses provide meaningful results for the conclusion of this study. These tables (Tables 2-4) show the results for year 30.

6.1 Baseline simulation

Table 1 presents the effects of rationalization that occur in years 1, 15, and 30 in the baseline simulation, while Figures 1 and 2 present the temporal changes in the selected variables. The figures illustrate that the variables start to approach a stable level (a new steady state) from around year 15 (except for the effort variable which starts to converge to the steady state from around year 10). Rationalization increases mackerel biomass by 72.1% and 74.5% in years 15 and 30, respectively (Table 1), relative to their pre-policy levels (see also Figure 1). Harvest falls by 49.5% immediately following rationalization (year 1), and its level is consistently lower than its pre-policy level (Figure 1). The before-policy TAC may have been set based on maximum sustainable yield (MSY) although the actual TAC in the base year is larger than the MSY. Results indicate that the economically optimal level of harvest (TAC) arising from rationalization is much lower than its base-year level.

The effects on effort are remarkable; the level of effort falls by over 60% relative to its pre-policy level (Figure 1) across 30 years. Due to the reduction in effort, the value of the marginal product of effort in the mackerel sector with the policy change is 49-57% higher than the factor prices throughout the simulation period, which are determined within the regional economy, resulting in a positive rent. The size of the reduction in harvest decreases with time (Figure 1) and the change in effort exhibits a similar pattern. This is because the stock recovers (Figure 1) from the reduced harvest, which raises the productivity of the fishery. Biomass in the base year was 44% of the carrying capacity. Rationalization increases the biomass to 77 % of the carrying capacity in year 30 (not shown).

The reduced harvest causes the price to increase – 18.4%, 13.0%, and 12.8%, respectively, in years 1, 15, and 30 (Figure 1). This price hike induces mackerel imports to increase significantly (by over 900% in year 30) and its exports to shrink (by 55.6% in year 30) (Table 1). On one hand, the increase in mackerel imports from Busan will benefit the rest of the world (the rest of Korea and foreign countries) by increasing the revenue of the fish-producing sectors in the rest of the world. On the other hand, it may have negative effects on the fisheries in the rest of the world if it results in increased pressure on the unregulated stocks in the rest of the world due to the increased demand from Busan. While the market prices of the factors of production do not change substantially, the actual returns to the factors remaining in the mackerel sector increase tremendously, by over 160% with the actual factor incomes increasing by 2.4 and 2.8% in years 15 and 30, respectively, reflecting the substantial rent increase (Table 1 and Figure 1). However, in the year immediately following the policy change, the factor income decreases due to a substantial reduction in harvest.

In each year beyond year 15, the rent is over 220% higher (about 142% higher in year 1) than its pre-policy level (Figure 1). The size of the change in rent depends on the relative strength of the changes in different variables, including the price of value-added, level of harvest, unit cost of effort, and amount of effort. The value-added price of mackerel rises from 0.670 (pre-policy) to 0.861 in the first year with the rationalization and then converges to 0.804 as the economy approaches a new steady state (not shown). Although the harvest declines, the significant reduction in effort coupled with the rise in the value-added price results in a rent increase.

Despite a substantial rent increase, the welfare of the mackerel sector households deteriorates (Table 1, Figure 2) mostly driven by a large reduction in effort; their welfare decreases by 22.5% in the year immediately following the rationalization, or by about 18.9 billion KRW ($16.6 million). In the following years, the welfare decrease stays below 8 billion KRW. The per capita welfare of the remaining mackerel sector households, however, increases by more than 150% over the simulation period due to a significant rent increase. The welfares of the other three types of households decrease. In particular, the welfare of all other households (non-seafood-producing households) diminishes significantly, especially in the early years following rationalization (Table 1, Figure 2). Because both the mackerel harvesting and seafood processing sectors produce less, the demand from these sectors for intermediate inputs from the non-seafood industries shrinks, leading to lower output in the industries and lower income and welfare of the households. Another reason why all other households' welfare decreases in the baseline simulation is that the capital released from the mackerel sector is not absorbed in the non-seafood industries but exits the region. Consequently, the output and value-added of non-seafood industries shrink, leading to a smaller welfare of the households relying on non-seafood industries. A higher price of mackerel, which is consumed by all other households as well as the other three types of households, also contributes to the deterioration of the welfare of this type of households.

Aggregate regional welfare (Figure 2) is consistently lower across the simulation years than its pre-policy level. The sum of the stream of the present discounted values (SSPDVs) of the aggregate regional welfare decreases by 0.078%, 0.057%, and 0.053%, respectively, in years 1, 15, and 30 (Table 1)[20]. This result implies that the benefits (rent) generated from rationalization are not large enough to compensate for the welfare loss of the households in the region.

How the rent is distributed depends on the specific institutional design. In our study, it is assumed that rent is distributed to labor and capital. It could be alternatively assumed that the rent is distributed to only one of the factors, or that the whole rent is taxed away by the regional government or the national government. Distribution of property rights is a policy choice. One potential policy might be to tax away the rent by the national government. The national government then may or may not transfer the tax revenue to the regional government. If the national government keeps the revenue, the tax revenue will be a leakage of income from the region, lowering the aggregate regional welfare. If instead the national government transfers the tax revenue to the regional government, the regional government will spend the money within the region, increasing the aggregate regional welfare. In either case, the mackerel households' welfare will be lower than when the rent is distributed to the factors of production only. While interesting, we did not examine how different policies regarding the rent distribution will affect the model results. A future study might investigate this issue. Results from the present study indicate that even without the rent leakage, the aggregate regional welfare can deteriorate due to out-migration of production factors.

6.2 Sensitivity analysis: Factor mobility

In the baseline simulation, it was assumed that labor is mobile only within the region but that capital is mobile both inter-sectorally and inter-regionally. For the sensitivity test in this section, we first ran the model assuming that both factors are mobile both inter-sectorally and inter-regionally, simulating highly open regional factor markets. We then ran the model assuming that both factors are mobile only within the region, simulating closed regional factor markets. This assumption was employed in a few studies (Apriesnig 2017, Congar and Hotte 2021).

The results illustrate that the SSPDVs of the aggregate regional welfare with highly mobile factors decreases by 0.323% (Table 2, last column) while it decreases by only

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[20] We used the discount rate of 4.5% (Ministry of Economy and Finance (2018)).

0.053% with the baseline simulation (3rd column), compared to its pre-policy level. This occurs because, with higher factor mobility, both labor and capital discharged from the rationalized fishery are not absorbed in the non-seafood industries in the region, but leak out of the region (with infinitely elastic factor supply curves), leading to the output and value-added in the non-seafood industries decreasing, whereas, in the baseline simulation, one of the factors (labor) from the rationalized sector flows to the non-seafood industries within the region.

When labor and capital are mobile only within the region (closed factor markets), the total output in the non-seafood industries increases due to rationalization while it decreases in the baseline simulation. This occurs as all the labor and capital from the mackerel harvesting and seafood processing sectors move to the non-seafood industries. The higher level of production in the non-seafood industries generates a larger value-added and consequently brings about an increase in the welfare of the households earning income from the non-seafood industries. The increase in the welfare of all other households is large enough to compensate for the welfare losses suffered by the other three types of households with a net increase in aggregate regional welfare. The SSPDVs of the aggregate regional welfare with the closed regional factor markets increases by 0.035% over the 30 years (Table 2).

We also computed changes in per capita welfare accounting for the change in the regional population (Table 2, last row). In the baseline simulation (Table 2, 3rd column) and in the case of closed factor markets (Table 2, 2nd column), the total local labor endowment is constant. Because the population does not change in these two different cases (baseline simulation and closed factor markets case), the percentage change in the aggregate regional welfare equals the percentage change in the per capita welfare (Table 2, the penultimate and last rows).

In the case of open factor markets case (Table 2, 4th and 5th column), the size of the post-policy regional population will be smaller than that in the baseline simulation due to labor out-migration. The sign and magnitude of the change in per capita welfare in the open factor markets case depend on the relative size of the percent reduction in the aggregate regional welfare and the percent reduction in the population size in each period. Table 2 shows that when the two factors of production are perfectly mobile (Table 2, 5th column), that is, when the factor migration elasticities are infinite, the aggregate regional welfare decreases by 0.323% but the per capita welfare increases by 0.084.

We also simulated the model with imperfect labor mobility represented by a less-than-infinite labor migration elasticity (0.137, Plaut 1981; Seung and Kraybill 2001)[21]. We

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[21] To model imperfect labor mobility, we used the following labor migration function. $LMIG_t = LSTK_t \cdot \left[\left(\frac{W_t}{W_{ROW}}\right)^{lme} - 1\right]$ where $LMIG_t$, $LSTK_t$, W_t, W_{ROW}, and *lme* denote, respectively, labor in-(out-)migration, total labor stock, wage rate in the region, wage rate in the rest of the world, and labor migration elasticity.

found that the per capita welfare decreases by 0.029 (Table 2, 4th column). Although not reported in the paper, we found that the smaller the labor migration elasticity, (i) the smaller the increase in the per capita welfare when it increases, and (ii) the larger the decrease in the welfare when it decreases.

The finding that aggregate regional welfare improves when regional factor markets are not integrated with outside factor markets is similar to the finding in Gilliland et al. (2022) that the aggregate regional welfare increases slightly in the long run. This similarity may be associated with a similar factor market assumption; in both cases, the total stocks of labor and capital in the study region are fixed, although Gilliland et al. (2022) used more restrictive assumptions that capital is fixed in each industry both before and after the policy reform. In our study, the four different factor market assumptions do not produce significantly different results for the effects on other variables for the mackerel sector (price, rent, harvest, effort, and biomass) (Table 2), but yield substantially different results for aggregate and per capita welfare changes. The findings from the sensitivity analysis for factor mobility highlight the importance of correctly specifying the factor markets and mobility in the study region (Seung 2024).

6.3 Sensitivity Analysis: Ratio of biomass to carrying capacity (*N/KC*)

The results of the sensitivity test for the ratio of biomass to the carrying capacity (*N/KC* ratio) indicate that the initial stock level is critical in determining the effects of rationalization. As shown in Table 3, as the *N/KC* ratio becomes lower, the biomass grows faster, increasing the productivity of the fishery, and resulting in a smaller decrease in the harvest. Although fish price rises by less as the *N/KC* ratio becomes lower, the smaller decrease in harvest and a larger decrease in effort leads to a significant increase in rent. Consequently, the SSPDVs of welfare changes for all types of households and the aggregate household decrease by less as the *N/KC* ratio becomes lower. This sensitivity test highlights the importance of correctly assessing the base-year stock level because the effects of rationalization may differ substantially depending on the level.

6.4 Sensitivity analysis: Catchability parameter

As previously mentioned, the rationalization-induced increase in catchability is one channel through which fishing efficiency may be improved. In this section, catchability is exogenously increased by 10%, 20%, and 30%, when simulating the rationalization. The change in catchability substantially affects the results (Table 4). An increase in the catchability leads to an increase in the marginal productivity of effort. This induces harvest to decrease by less and effort to decrease by more, contributing to a substantial increase in the resource rent, despite a decrease in the fish price. In the baseline simulation, the rent increases by 228.5% in year 30 while it increases by 305.6% with a 30% increase in the catchability in the same year. However, the increase in productivity is not large enough to incentivize the fishermen to increase their harvest above its pre-policy level. Even when the catchability parameter is increased by 30%, the harvest level in year 30 is much lower (18.5% lower) than its pre-policy level. As a result, the SSPDVs of the aggregate regional welfare decreases (by 0.036%) even when the catchability increases by as much as 30%.

6.5 Discussion

Rationalization reduces harvest and releases some of the labor and capital from the mackerel sector in the first several years following rationalization. In the baseline simulation, the released labor flows to non-mackerel industries in Busan and the released capital exits the region. Under these circumstances, the mackerel price rises due to the reduced harvest, the wage rate in the region falls due to an increased supply of labor in the non-mackerel industries, and the non-seafood industries' production decreases due to the reduced demand from the mackerel sector. This results in a decrease in the aggregate regional welfare although the resource rent in the rationalized sector increases. In the longer term, the fish stock recovers, and both effort and harvest increase at a decreasing rate, approaching their steady-state levels over time. However, results from the baseline simulation indicate that the increase in the harvest is not large enough to make the aggregate regional welfare to increase in the longer term.

If the factor markets are completely open to outside economies (in a sensitivity analysis), the negative impacts of the policy on the aggregate regional welfare are larger than in the baseline simulation. However, if the factor markets are closed to the outside economies (in the sensitivity analysis), as in Apriesnig (2017) and Gilliland et al. (2022), the aggregate regional welfare increases. We found from the sensitivity analysis for factor mobility that the regional aggregate regional welfare and per capita welfare can increase or decrease depending on the assumptions about inter-regional factor mobility. Therefore, whether the per capita welfare increases or decreases due to a fishery management policy is an empirical matter that can be investigated within an empirical general equilibrium model. This particular study elucidates that fishery rationalization can decrease aggregate regional welfare and per capita welfare under certain factor market conditions (i.e., in the baseline simulation and with less-than-infinite labor migration elasticity).

Note that when the fishing capital exits the region in the baseline simulation and when the factor markets are completely open, we assumed that the capital owners follow the capital, meaning that they move out of the region when the capital exits the region, in which case the fishing capital disappears from the region. If the capital owners still stay in the region after the leakage of the capital, they will earn income generated in a non-Busan region and this income will be added to Busan's total income. But because the capital is not used in the non-seafood industries in Busan, the direct, indirect, and induced effects that would be generated if this capital were used in these non-seafood industries, will be lost. Modeling this case requires a multi-regional CGE framework because the capital income is generated outside the study region.

We found from the baseline simulation that the post-policy level of harvest never surpasses its pre-policy level over time (Figure 1) even though the stock increases by as much as 74.5% by year 30 compared to its pre-policy level, limiting the return of the released labor and capital to the regional industries including the mackerel sector, and resulting in a decrease in the aggregate (and per capita) welfare. This outcome contrasts with (i) the results from a sensitivity analysis where the closed factor markets are simulated in the present study and (ii) the findings of Gilliland et al. (2022) and Manning et al. (2016) that the fishery reform [reduction in fishing capital in case of Manning et al. (2016)] brings about short-term losses in aggregate regional welfare (real income) but long-term gains are generated because of the recovery of biomass.

The difference between the welfare outcomes from our baseline simulation and those of the two previous studies [Gilliland et al. (2022) and Manning et al. (2016)] may be associated with the pre-policy level of the stock relative to its carrying capacity. In our study, the base-year ratio of biomass to its carrying capacity (*N/KC* ratio) is 0.443, which is higher than those in the previous studies—0.36 in Gilliland et al. (2022) and 0.20 in Manning et al. (2016). The higher *N/KC* ratio for Busan's mackerel may be a result of the government's efforts to manage the fishery effectively using regulations such as license limitations and TAC. By contrast, the fisheries in the previous studies are pure open access, where stocks are much more heavily overexploited. Although some restrictions exist, they are rarely enforced. We conducted a sensitivity analysis where we lowered the *N/KC* ratio by 20% and 40% and found that the lower the ratio, the larger the effects of the policy on biomass, rent, and effort.

Our study shows that the rationalization of Busan's mackerel fishery generates economic effects not only on the rationalized fishing sector and other sectors of the regional economy but also on other regions within the country. The total national welfare of the residents within the country will increase due to the regional fishery rationalization. However, some of the benefits of the policy will flow to non-Busan regions. From the national government's perspective, leakage of the benefits represents simply a reallocation of the benefits over space. Our study adopts the local (regional) policymakers' perspective and focuses on the local welfare effects of rationalization with mobile factor markets, that is, the welfare of the residents of the region where the policy is implemented. We found that the aggregate local (regional) welfare can decrease if the factors of production released from the regulated sector are not absorbed in the non-regulated sectors in the local economy but exit the region, as shown by the welfare results. That said, our study is not about overall national welfare or efficiency, but about how some of the overall benefits of the policy can flow out of the region where the policy is implemented.

The government is currently planning to adopt an ITQ system for the Busan mackerel fishery. The results from our study reveal that while the remaining mackerel sector households may benefit from rationalization through a substantial rent increase, the other three types of households may suffer welfare losses. Therefore, it is not surprising that some stakeholders (especially seafood processors) object to the plan because a rationalization will leave them worse off. If the government wishes to compensate those bearing the cost of an ITQ program, it should consider a policy that compensates for the loss suffered by the processors.

7. Conclusions

Previous studies assessing the economy-wide effects of fishery rationalization did not pay much attention to the role of factor mobility in determining its welfare effects and predicted that the aggregate regional welfare increases. Our study found that this is not necessarily the case if factors are highly mobile among regions. We first simulated the effects of rationalization assuming that one or both of the factors of production are inter-regionally mobile and the initial level of the fish stock is relatively high (in baseline simulation). We found from this simulation that the long-run increase in harvest due to rationalization is not sufficiently large to surpass its pre-policy level so that the aggregate regional welfare can improve over 30 years. Our study reveals that the benefits of rationalization may accrue only to the remaining mackerel sector households and are not large enough to compensate for the welfare loss suffered by the other three types of households. However, we found from sensitivity analyses that the aggregate regional welfare improves in the long term if fishing capital released from the rationalized sector is absorbed by the non-fishing sectors within the region.

The finding that aggregate regional welfare decreases in some cases has important policy implications. The Korean government may need to be aware that the rationalization of Busan’s mackerel fishery can lead to some households (seafood processing households and all other households) being worse off than now. Therefore, when the government designs a rationalization scheme for fisheries, it may need to devise measures to compensate for the welfare loss of these groups.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 1 Effects of Rationalization for mackerel fishing sector and welfare (baseline simulation)

	Year 1	Year 15	Year 30
Mackerel sector (percent of the benchmark)			
Biomass	0.00	72.1	74.5
Harvest	-49.5	-29.2	-28.8
Fish price	18.4	13.0	12.8
Rent	141.9	226.4	228.5
Effort	-70.9	-63.7	-63.7
Market wage rate	-0.017	-0.012	-0.012
Market return to capital	0	0	0
Actual wage rate	168.4	182.2	183.3
Actual return to capital	168.5	182.2	183.3
Actual labor income	-22.0	2.4	2.8
Actual capital income	-22.0	2.4	2.8
Imports	1980.7	975.7	956.4
Exports	-73.9	-56.0	-55.6
Welfare change (billion KRW, not discounted)			
Mackerel sector households	-18.9	-8.0	-7.8
Non-mackerel sector households	-3.5	-2.8	-2.7
Seafood processing households	-4.1	-3.2	-3.2
All other households	-13.9	-10.5	-10.4
Aggregate regional welfare change	-40.5	-24.5	-24.1
Welfare change (sum of the stream of present discounted values, percent of benchmark)			
Mackerel sector households	-22.5	-13.6	-12.3
Mackerel sector households (per capita)	166.7	150.6	150.4
Non-mackerel sector households	-1.7	-1.4	-1.4
Non-mackerel sector households (per capita)	-1.7	-1.4	-1.4
Seafood processing households	-4.2	-3.6	-3.4
Seafood processing households (per capita)	1.5	1.3	1.3
All other households	-0.027	-0.023	-0.022
All other households (per capita)	-0.049	-0.042	-0.041
Aggregate regional welfare change	-0.078	-0.057	-0.053
Aggregate regional welfare change (per capita)	-0.078	-0.057	-0.053

Note: In this simulation, the CGE model used the parameters in Table B.3 to calculate the effects of rationalization. The percentage change in the per capita welfare is defined for the remaining households or residents.

Table 2 Results from sensitivity test for factor mobility (Year 30)

	Closed factor markets	Baseline simulation	Open factor markets (imperfectly mobile labor)	Open factor markets (perfectly mobile labor)
Mackerel sector (percent of the benchmark)				
Biomass	74.5	74.5	74.5	74.5
Harvest	-28.8	-28.8	-28.8	-28.8
Fish price	12.9	12.8	12.8	12.8
Rent	228.9	228.5	228.3	228.1
Effort	-63.7	-63.7	-63.7	-63.7
Welfare change (sum of the stream of present discounted values, percent of benchmark)				
Mackerel sector households	-12.2	-12.3	-12.3	-12.3
Mackerel sector households (per capita)	150.7	150.4	150.4	150.5
Non-mackerel sector households	-1.3	-1.4	-1.4	-1.5
Non-mackerel sector households (per capita)	-1.2	-1.4	-1.5	-1.5
Seafood processing households	-3.4	-3.4	-3.5	-3.6
Seafood processing households (per capita)	1.4	1.3	1.3	1.3
All other households	0.067	-0.022	-0.072	-0.292
All other households (per capita)	0.048	-0.041	-0.009	0.097
Aggregate regional welfare change	0.035	-0.053	-0.103	-0.323
Aggregate regional welfare change (per capita)	0.035	-0.053	-0.029	0.084

Note: In this sensitivity analysis, we compare the results from four different factor market assumptions: (i) both labor and capital are mobile only within the region (closed factor market), (ii) capital is perfectly mobile while labor is mobile only within the region (baseline simulation), (iii) capital is perfectly mobile while labor is imperfectly mobile between regions, and (iv) both labor and capital are perfectly mobile (open factor market). The percentage change in the per capita welfare is defined for the remaining households or residents.

Table 3 Results from the sensitivity test for the ratio of biomass to carrying capacity (*N/KC)* (Year 30)

	Baseline simulation	20% lower	40% lower
Mackerel sector (percent of the benchmark)			
Biomass	74.5	118.7	200.8
Harvest	-28.8	-23.6	-17.7
Fish price	12.8	11.2	9.1
Rent	228.5	260.2	301.0
Effort	-63.7	-65.0	-68.1
Welfare change (sum of the stream of present discounted values, percent of benchmark)			
Mackerel sector households	-12.3	-10.7	-9.0
Mackerel sector households (per capita)	150.4	164.1	186.9
Non-mackerel sector households	-1.4	-1.3	-1.2
Non-mackerel sector households (per capita)	-1.4	-1.3	-1.2
Seafood processing households	-3.4	-3.3	-3.0
Seafood processing households (per capita)	1.3	1.2	1.1
All other households	-0.022	-0.020	-0.018
All other households (per capita)	-0.041	-0.039	-0.036
Aggregate regional welfare change	-0.053	-0.049	-0.043
Aggregate regional welfare change (per capita)	-0.053	-0.049	-0.043

Note: In this sensitivity analysis, we compare the results from lowering or increasing the initial ratio of biomass to carrying capacity with those from baseline simulation. The percentage change in the per capita welfare is defined for the remaining households or residents.

Table 4 Results from sensitivity test for catchability (Year 30)

	Baseline simulation (No change)	10% increase	20% increase	30% increase
Mackerel sector (percent of the benchmark)				
Biomass	74.5	69.9	65.9	62.7
Harvest	-28.8	-24.5	-21.1	-18.5
Fish price	12.8	11.5	10.4	9.4
Rent	228.5	258.1	283.6	305.6
Effort	-63.7	-65.4	-67.5	-69.7
Welfare change (sum of the stream of present discounted values, percent of benchmark)				
Mackerel sector households	-12.3	-9.6	-7.6	-6.1
Mackerel sector households (per capita)	150.4	165.3	183.8	205.2
Non-mackerel sector households	-1.4	-1.3	-1.2	-1.1
Non-mackerel sector households (per capita)	-1.4	-1.3	-1.2	-1.1
Seafood processing households	-3.4	-3.2	-3.0	-2.8
Seafood processing households (per capita)	1.3	1.2	1.1	1.0
All other households	-0.022	-0.020	-0.018	-0.017
All other households (per capita)	-0.041	-0.038	-0.035	-0.033
Aggregate regional welfare change	-0.053	-0.047	-0.040	-0.036
Aggregate regional welfare change (per capita)	-0.053	-0.047	-0.040	-0.036

Note: In this sensitivity analysis, we compare the results from increasing the catchability parameter by 10, 20, and 30%, respectively, with those from baseline simulation. The percentage change in the per capita welfare is defined for the remaining households or residents.

Figure 1 Effects of rationalization (as a percent of before-policy level)

Note: Harvest and biomass are in tons. Price is defined for one unit of harvest. Rent is in million KRW. Effort is the sum of labor and capital in the base year. One unit of effort costs 1 million KRW in the base year.

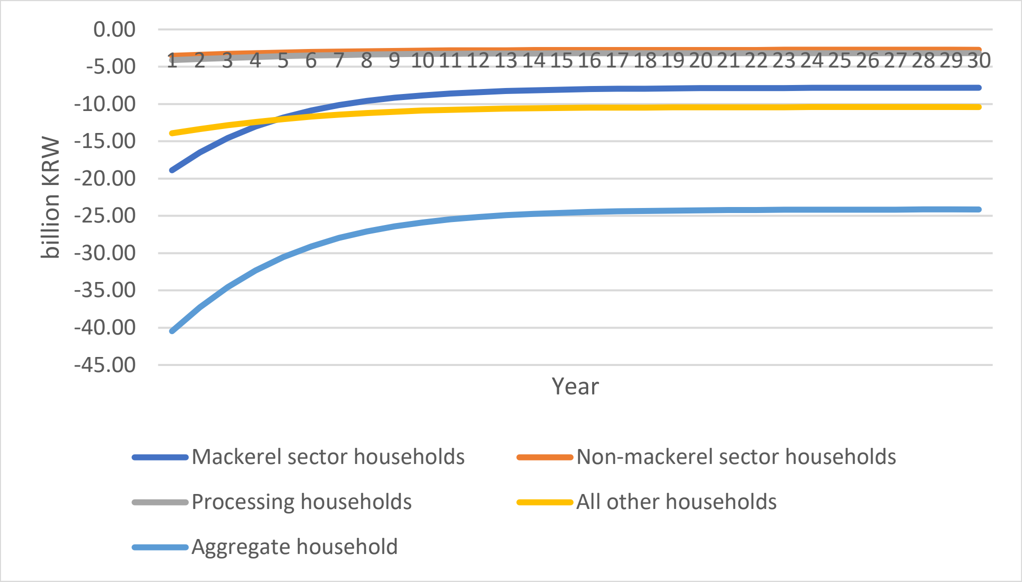

Figure 2 Welfare effects of rationalization (billion KRW, not discounted)

Note: Welfare change is measured in equivalent variation, i.e., the difference between the expenditure function evaluated at before-policy utility and prices and the expenditure function evaluated at after-policy utility and before-policy prices.

Appendix A

This appendix presents equations, variables, and parameters used in the Busan CGE model. The equations presented are for performing the baseline simulation.

A.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; *h* and *hh* denote household types; *fhh* (= *fs*), *sph* (= *sp*), and *oth* (= *nsp*) denote, respectively, fish harvesting households (mackerel sector households and non-mackerel sector households), seafood processing households, and all other households. These sets (*fhh, sph*, and *oth*) are subsets of *h*. Subscript *t* denoting period (time) is suppressed for simplicity in the equations except in the objective function, the search cost updating equation, and the population dynamics equation (Equations 10, 56, and 57 below).

Prices

Definition of regional import prices:

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

Description: Import supply is infinitely elastic.

Definition of regional export prices:

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

Description: Export demand is infinitely elastic.

Definition of composite good prices:

$$PQ_c Q_c = PD_c D_c + PM_c M_c \tag{3}$$

Definition of regional sales prices:

$$PD_c D_c = PZ_c Z_c - PE_c E_c \tag{4}$$

Definition of regional industry prices:

$$PX_i = \sum_c \Delta_{i,c} PZ_c \tag{5}$$

Description: The price of industry output is transformed from the commodity price using make matrix

Definition of activity prices:

$$PV_i = PX_i - \sum_c a_{c,i} PQ_c - itr_i PX_i \tag{6}$$

Production and Input Demand

<u>Fish harvesting industries</u>

Harvesting function:

$$X_{fs} = f(E_{fs}) = d_{fs} E_{fs}{}^{f_{fs}} N_{fs}{}^{g_{fs}} \tag{7}$$

Description: Harvest is a Cobb-Douglas function of effort and biomass

The unit cost of effort function:

$$C_{fs} = \frac{1}{\Psi_{fs}} \left[\alpha_{fs}{}^{\sigma_{fs}} W^{(1-\sigma_{fs})} + (1-\alpha_{fs})^{\sigma_{fs}} R^{(1-\sigma_{fs})} \right]^{\frac{1}{(1-\sigma_{fs})}} \tag{8}$$

Description: Unit cost of effort is derived by minimizing the effort cost subject to a constant elasticity of substitution (CES) effort function.

Effort demand function (regulated open access fishery)

$$\frac{k_{fs} PV_{fs} X_{fs}}{E_{fs}} = C_{fs} \tag{9}$$

Description: Effort demand is the first-order condition of profit maximization

Objective function (rationalized fishery)

$$\text{Max } OBJ = \sum_t^T \frac{1}{(1+d)^t} \left(PV_{mc,t} H_{mc,t} - C_{mc,t} E_{mc,t} \right), \tag{10}$$

Description: Effort demand and harvest are determined via maximizing the objective function.

Level of stock in the first period:

$$N_{mc,TF} = N_{mc,0} \tag{11}$$

Description: The level of stock in the first period is equal to its base-year level.

Last period condition:

$$HARV_{mc,TL} = N_{mc,TL} + \gamma_{mc} N_{mc,TL} \left(1 - \frac{N_{mc,TL}}{KC_{mc}} \right) \tag{12}$$

Description: The level of harvest in the last period (TL) equals the growth of the mackerel stock.

The labor demand function for fish harvesting:

$$L_{fs} = \left(\frac{E_{fs}}{\Psi_{fs}} \right) \left[\frac{(1-\alpha_{fs}) \Psi_{fs} C_{fs}}{W} \right]^{\sigma_{fs}} \tag{13}$$

Description: Labor demand in the fishery is derived by minimizing the effort cost subject to a CES effort function.

The capital demand function for fish harvesting:

$$K_{fs} = \left(\frac{E_{fs}}{\Psi_{fs}}\right)\left[\frac{\alpha_{fs}\Psi_{fs}C_{fs}}{R}\right]^{\sigma_{fs}} \tag{14}$$

Description: Capital demand in the fishery is derived by minimizing the effort cost subject to a CES effort function.

Non-fishing industries

Unit cost function:

$$UC_{nfs} = \frac{1}{\Phi_{nfs}}[\alpha_{nfs}{}^{\sigma_{nfs}} R^{(1-\sigma_{nfs})} + (1-\alpha_{nfs})^{\sigma_{nfs}} W^{(1-\sigma_{nfs})}]^{\frac{1}{(1-\sigma_{nfs})}} \tag{15}$$

Description: Unit cost for non-fishing industries is derived by minimizing the cost of production subject to a CES value-added function.

Labor demand function:

$$L_{nfs} = \left(\frac{X_{nfs}}{\Phi_{nfs}}\right)\left[\frac{(1-\alpha_{nfs})\Phi_{nfs}UC_{nfs}}{W}\right]^{\sigma_{nfs}} \tag{16}$$

Description: Labor demand in non-fishing industries is derived by minimizing the cost of production subject to a CES value-added function.

Capital demand function:

$$K_{nfs} = \left(\frac{X_{nfs}}{\Phi_{nfs}}\right)\left[\frac{\alpha_{nfs}\Phi_{nfs}UC_{nfs}}{R}\right]^{\sigma_{nfs}} \tag{17}$$

Description: Capital demand in non-fishing industries is derived by minimizing the cost of production subject to a CES value-added function.

Intermediate demand of sector i for commodity c:

$$ND_{c,i} = a_{c,i}X_i \tag{18}$$

Description: Intermediate input demand is proportional to output

Definition of regional commodity output:

$$Z_c = \sum_i \Delta_{i,c}X_i \tag{19}$$

Description: Commodity output is transformed from industry output using the make matrix.

Zero profit condition for non-fishing industries:

$$PV_{nfs}X_{nfs} = W \cdot L_{nfs} + R \cdot K_{nfs} \tag{20}$$

Household Demand

Household consumption demand:

$$HC_{c,h} = \frac{\beta_{c,h} HEXP_h}{PQ_c^{\gamma_h} \sum_c \beta_{c,h} PQ_c^{(1-\gamma_h)}} \tag{21}$$

Description: Household demand for goods is derived by maximizing a CES utility subject to budget constraints.

Income Block

Total labor income for fishing households:

$$YL_{fhh} = W \cdot L_{fs} + \theta_{L,fs}(PV_{fs}X_{fs} - C_{fs}E_{fs}) \tag{22}$$

Total labor income for seafood processing households:

$$YL_{sph} = W \cdot L_{sp} \tag{23}$$

Total labor income for all other households:

$$YL_{oth} = \sum_{nsp} W \cdot L_{nsp} \tag{24}$$

Total capital income for fishing households:

$$YK_{fhh} = R \cdot K_{fs} + \theta_{K,fs}(PV_{fs}X_{fs} - C_{fs}E_{fs}) \tag{25}$$

Total capital income for seafood processing households:

$$YK_{sph} = R \cdot K_{sp} \tag{26}$$

Total capital income for all other households:

$$YK_{oth} = \sum_{nsp} R \cdot K_{nsp} \tag{27}$$

Labor income after leakage:

$$YLL_h = (1 - wleakr)YL_h \tag{28}$$

Capital income after leakage, national and regional taxes, and enterprise savings:

$$YKK_h = (1 - rleakr - ktrng - ktrrg - esrate)YK_h \tag{29}$$

Household factor income:

$$YH_h = YLL_h + YKK_h \tag{30}$$

Total household income:
$$TYH_h = YH_h + RTR_h + REMH_h \tag{31}$$

Household expenditure:
$$HEXP_h = (1 - trng_h - trrg_h - MPS_h)TYH_h \tag{32}$$

National and Regional Governments

National government revenue:
$$NGREV = ngibt \textstyle\sum_i (itr_i) PX_i X_i + (ktrng)YK + \sum_h (trng_h) TYH_h \tag{33}$$

National government expenditure:
$$NGEXP = \textstyle\sum_c PQ_c CNG_c + TRANR \tag{34}$$

National government demand for commodities:
$$PQ_c CNG_c = (ngles_c) NGDTOT \tag{35}$$

Regional government revenue:
$$RGREV = ribt \textstyle\sum_i (itr_i) PX_i X_i + (ktrrg)YK + \sum_h (trrg_h) TYH_h + TRANR \tag{36}$$

Regional government expenditure:
$$RGEXP = \textstyle\sum_c PQ_c CRG_c + \sum_h RTR_h \tag{37}$$

Regional government demand for commodities:
$$PQ_c CRG_c = (rgles_c) RGDTOT \tag{38}$$

National government transfer to regional government:
$$TRANR = (\ nrrat\ ) NGREV \tag{39}$$

Savings and Investment

Household savings:
$$HSAV_h = (MPS_h) TYH_h \tag{40}$$

Enterprise savings:
$$ENTSAV_h = (esrate)\, YK_h \tag{41}$$

National government savings:
$$GSN = NGREV - NGEXP \tag{42}$$

Regional government savings:
$$GSR = RGREV - RGEXP \tag{43}$$

External savings:

$$FSAV = \sum_c PM_c M_c - \sum_c PE_c E_c + (wleakr)\sum_h YL_h + (rleakr)\sum_h YK_h - \sum_h REMH_h \quad (44)$$

Total savings:

$$TSAV = \sum_h HSAV_h + \sum_h ENTSAV_h + GSN + GSR + (ER)FSAV \quad (45)$$

Investment by sector of origin:

$$ID_c = \frac{(invrat_c)\,ITOT}{PQ_c} \quad (46)$$

Description: Investment is determined by the base-year ratio of sectoral investment to the total regional investment

Exports and Imports

Supply aggregation function:

$$Z_c = A_c^T[\varphi_c E_c^{\theta_c} + (1-\varphi_c)D_c^{\theta_c}]^{\frac{1}{\theta_c}} \quad (47)$$

Description: Total commodity output is allocated to domestic and export markets through a constant elasticity of transformation (CET) function.

Export supply function:

$$E_c = \left(\frac{PE_c}{PD_c}\right)^{\Lambda_c}\left(\frac{1-\varphi_c}{\varphi_c}\right)^{\Lambda_c} D_c \quad (48)$$

Description: The export supply function is derived by maximizing the firm's revenue subject to the CET function

Demand aggregation function:

$$Q_c = A_c^C[\delta_c M_c^{-\rho_c} + (1-\delta_c)D_c^{-\rho_c}]^{-\frac{1}{\rho_c}} \quad (49)$$

Description: Total regional commodity demand is a CES aggregation of regionally produced and imported versions of the commodity

Import demand function:

$$M_c = \left(\frac{PD_c}{PM_c}\right)^{\upsilon_c}\left(\frac{\delta_c}{1-\delta_c}\right)^{\upsilon_c} D_c \quad (50)$$

Description: Import demand for a commodity is derived by minimizing the consumers' expenditures on the commodity subject to a CES aggregation function

Equilibrium Conditions

Goods market equilibrium:

$$Q_c = \sum_h HC_{c,h} + \sum_i ND_{c,i} + ID_c + CNG_c + CRG_c \quad (51)$$

Labor market equilibrium condition:

$$LTOT_i = \sum_i L_i \quad (52)$$

Description: The total labor stock available in the region is fixed, which implies that the market wage rate is endogenous.

Capital market equilibrium condition:

$$R = RB \quad (53)$$

Description: Return to capital is fixed and equal to the return to capital in the rest of the world, which means that the total capital stock available in the region is endogenous.

Gross Regional Product

Gross regional product at market prices:

$$GRP = \sum_i [PV_i X_i + itr_i PX_i X_i] \quad (54)$$

Real gross regional product:

$$RGRP = \sum_c \left[\sum_h HC_{c,h} + ID_c + CNG_c + CRG_c + E_c - M_c\right] \quad (55)$$

Model Closure

The following variables are fixed at their base-year levels: ER, NGDTOT, N_{fs}, ITOT, LTOT, R, RGDTOT. In addition, H_{nmc} (non-mackerel harvest) is fixed at its base-year level.

The above equations with model closures are solved for each period with the values of the biomass (N_t) and the input-output coefficient for fuel (a_fuel_t), which are updated at the end of each period using the following two equations (Equations 56 and 57).

Dynamics

Search cost function:

$$a\_fuel_t = \frac{GFL}{(N_t)^n}, \quad (56)$$

Description: Input-output coefficient for fuel has an inverse relationship with the level of biomass

Logistic growth function:

$$N_{t+1} = N_t + \gamma N_t \left(1 - \frac{N_t}{KC}\right) - HARV_t \tag{57}$$

Description: Biomass in the next period is the biomass in the current period plus its change due to fish growth and harvest.

A.2 List of Endogenous Variables

CNG_c	National government demand for commodity *c*
C_{fs}	Unit cost of fish harvesting effort
CRG_c	Regional government demand for commodity *c*
D_c	Quantity of locally produced and consumed commodity *c*
E_c	Quantity of exported commodity *c*
EF_{fs}	Effort in fish harvest function
$ENTSAV_h$	Enterprise savings for *h*
ER	Exchange rate
NGDTOT	National government expenditure on commodities
NGEXP	Total national government expenditure
NGREV	National government revenue
FSAV	External savings
GRP	Gross regional product at market prices
GSN	National government savings
GSR	Regional government savings
$HC_{c,h}$	Household *h*'s demand for commodity *c*
$HEXP_h$	Household *h*'s expenditure
$HSAV_h$	Household *h*'s savings
ID_c	Aggregate investment demand for commodity *c*
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*
LTOT	Aggregate labor demand
M_c	Quantity of imported commodity *c*
N_{fs}	Fish population
$ND_{c,i}$	Quantity of intermediate commodity *c* used by sector *i*
PD_c	Price of locally produced and consumed commodity *c*
PE_c	Price of exported commodity *c*
PM_c	Price of imported commodity *c*
PQ_c	Price of composite commodity *c*
PV_i	Net price of a unit of value-added in sector *i*
PX_i	Output price of good *i*
PZ_c	Price of commodity *c* produced in the region
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
TRANR	National government transfers to regional government
TSAV	Total savings
TYH_h	Total household income for household *h*
UC_i	Unit cost for sector *i*
W	Market wage rate
X_i	Industry output in sector *i*
YH_h	Household *h*’s factor income
YK_h	Total capital income
YKK_h	Capital income after leakage, national and regional taxes, and enterprise savings
YL_h	Total labor income
YLL_h	Labor income after leakage
Z_c	Output of commodity *c*

A.3 List of Exogenous Variables

R	Market return to capital
REMH_h	Remittances from the rest of the world
RTR_h	Regional government transfers to household *h*
PWE_i	Rest of world price of exported good *i*
PWM_i	Rest of world price of imported good *i*

A.4 List of variables updated in each period

N_t	Biomass in period *t*
a_fuel_t	Input-output coefficient for fuel in period *t*

A.5 List of Parameters

Import Demand

A_c^C	Armington function shift parameter
δ_c	Armington function share parameter
ρ_c	Armington function exponent
υ_c	Elasticity of substitution between imports and local goods

Production

$\Delta_{i,c}$	Row-sum normalized make matrix
$a_{c,i}$	Technical coefficients
Φ_i	Value-added function shift parameter for non-fishing industries
α_i	Value-added function share parameter for non-fishing industries

σ_i	Value-added function exponent for non-fishing industries
Ψ_{fs}	Effort function shift parameter for fishing industries
α_{fs}	Effort function share parameter for fishing industries
σ_{fs}	Effort function exponent for 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

Export Supply

A_c^T	CET function shift parameter
φ_c	CET function share parameter
θ_c	CET function exponent
Λ_c	Elasticity of transformation

Consumption

$\beta_{c,h}$	Expenditure share for commodity *c*: household *h*
γ_h	Elasticity of substitution for household *h*

Budget of Household

wleakr	Labor income leakage rate
rleakr	Capital income leakage rate
esrate	Enterprise savings rate
MPS_h	Marginal propensity to save for household *h*
$trrg_h$	Regional income tax rate for household *h*
$trng_h$	National income tax rate for household *h*

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

RB	Return to capital in the base year

Search cost updating

GFL	Parameter to reproduce the base-year value of the input-output coefficient for fuel
n	Fuel cost saving coefficient

Logistic growth function

γ	Intrinsic growth rate
KC	Carrying capacity

Appendix B

Table B.1 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 B.2 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 B.3 Parameter values used in the Busan CGE Model

Elasticities and Parameters	Value
Elasticity of Effort in Harvest Function [a]	
Mackerel fishing	0.554
Non-mackerel fishing	0.740
Elasticity of Stock in Harvest Function [a]	
Mackerel fishing	0.398
Non-mackerel fishing	0.810
Degree of openness in the fishery (pre-rationalization) [a]	
Mackerel fishing	0.832
Non-mackerel fishing	0.768
Elasticity of Substitution in Effort Function [b]	
Mackerel fishing and Non-mackerel fishing	0.61
Elasticity of Substitution in Production [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]	1.125
The elasticity of Substitution between Imports and Local Goods [d]	
Agriculture, Mackerel fishing, Non-mackerel fishing, Aquaculture, and Mining	1.42
Seafood processing	0.31
Construction	3.15
All manufacturing commodities except Seafood processing	3.55
All the other commodities	2.00
Elasticity of Transformation in Production: Regional Goods and Exports [e]	
Agriculture, Mackerel fishing, Non-mackerel fishing, Aquaculture, and Mining	3.9
All manufacturing commodities and Construction	2.9
All the other commodities	0.7
The numerator in the search cost function (GFL) [f]	
Mackerel fishing	6.7×10^{10}
Non-mackerel fishing	1.0×10^{10}
Fuel cost saving coefficient (n) [g]	2.0
Intrinsic growth rate in logistic growth function [h]	
Mackerel fishing	0.42
Non-mackerel fishing	1.32
Carrying capacity in logistic growth function [i]	
Mackerel fishing	1,419,923 tons
Non-mackerel fishing	491,044 tons

Source:
a Authors’ estimation
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)
d The elasticity values are based on de Melo and Tarr (1992, p. 231).
e The elasticity values are based on de Melo and Tarr (1992, p. 233).
f Calibrated given base-year values of input-output coefficients, biomass levels, and fuel cost-saving coefficient (*n*).
g Gilliland et al. (2022)
h Hong and Kim (2021) and the authors’ calculation
i Hong and Kim (2021) and authors’ calculation

Table B.4 Parameter values or assumptions used for sensitivity analyses for the mackerel fishing sector

Elasticity of substitution in Armington function

Low	Baseline	High
0.2	1.42	10

Elasticity of transformation in CET function

Low	Baseline	High
0.2	3.9	10

Factor mobility

Closed factor markets	Baseline	Open factor markets
Factors are mobile only within the region	Labor is mobile within the region. Capital is mobile between regions.	Factors are mobile between regions.

Catchability parameter

Baseline (No increase)	10% increase	20% increase	30% increase
1.379	1.517	1.655	1.793

Search cost function parameter (*n*)

Low	Baseline	High
0.2	2.0	10

Intrinsic growth rate

Low	Baseline	High
0.27	0.42	0.66

The ratio of biomass to carrying capacity (*N/KC*)

Baseline	20% lower	40% lower
0.443	0.354	0.266

Appendix C Parameterization and calibration

The effort and stock elasticities in Equation (1) were estimated using a linear transformation for the two fishing sectors using OLS. This study used 29 years (1992-2020) of time series data on fish harvest, effort (number of vessels), and biomass level. (KOSIS 2021; Hong and Kim, 2021). We used the number of vessels when estimating the effort elasticity due to the lack of usable time-series data on, and appropriate measures of, labor. We acknowledge the limitation that using only capital (vessels) as a proxy for effort may not be fully consistent with how we combined labor and capital in the effort function. To the extent that the number of vessels does not measure the level of effort accurately, the results could be over- or underestimated to some extent.

For the mackerel harvest function, the effort and stock elasticities were estimated to be 0.55 (p-value = 0.0002) and 0.40 (p-value = 0.03), respectively. Stock and effort elasticities in the mackerel harvest function suggest that the mackerel production exhibits decreasing returns to scale although it is very close to constant returns to scale (that is, the sum of the two elasticities is 0.952 which is close to 1). This means that there exists an inframarginal rent in addition to the resource rent. However, our study assumes that all the rent is resource rent, given that the production technology is very close to constant returns to scale. This implies that the inframarginal rent is distributed in the same way as the resource rent. The two elasticities in the non-mackerel harvest function were estimated to be 0.74 (p-value = 0.001) and 0.81 (p-value = 0.002), respectively. The value of the stock elasticity estimated for the fishery under study (0.40, mackerel) is the same as that in Manning et al. (2016), which assumes an elasticity value of 0.4 for an artisanal fishery in Honduras. Based on previous studies, Gilliland et al. (2022) chose a stock elasticity of 0.645 for a local area's fishery in the Philippines (El Nido on the island of Palawan). Other CGE studies estimated the harvest function econometrically. Finnoff et al. (2007), for instance, estimated the stock elasticity parameter to be 0.21 for the Alaska pollock fishery. Apriesnig (2017) estimated the harvest function for the Lake Erie yellow perch fishery in Ohio and obtains a stock elasticity value of 0.237.

Since both mackerel and non-mackerel fisheries are under a regulated open-access regime, some positive rent exists in these fisheries even before mackerel fishery is fully rationalized. To estimate the base year (2015) resource rent for the mackerel fishery, first of all, the average of five years' (2011–2015) net profits [National Federation of Fisheries Cooperatives (NFFC) 2022] of large purse seine fishery, which accounts for a dominant share (85.8%) of total mackerel catch in Korea, was divided by the average of the five years' ex-vessel revenues (KOSIS 2022) of the fishery, yielding the ratio of the net profit to the ex-vessel revenue. Next, this ratio was multiplied by the base-year ex-vessel revenue from Busan's mackerel fishery to obtain the net profit of the mackerel fishery. Finally, we split the net profit into the opportunity cost of capital and resource rent using information on the normal profit and resource rent estimated for Korean fisheries in Nam (2018). A similar procedure was used to estimate the base-year rent for the non-mackerel fisheries. The resource rents thus estimated are 22,739 million KRW and 79,593 million

KRW for the two fisheries in the base year, respectively. These numbers represent 11.3% and 15.8% of the base-year ex-vessel revenues of the two fisheries, respectively.

To calibrate the values of k for the two fishing sectors in Equation (5) under regulated open access, we first express rent as:

$$RENT = PV \cdot H - C \cdot E \,. \tag{C.1}$$

Using Equation (5) and Equation (C.1), rent can be expressed alternatively as:

$$RENT = (1 - k\,) \cdot PV \cdot H \,. \tag{C.2}$$

Given the base-year ex-vessel revenue ($PV \cdot H$) and an estimated value of the resource rent above for each fishing sector, this study calibrated the values of k using Equation (C.2). The values of k thus calibrated are 0.832 and 0.768 for mackerel and non-mackerel sectors, respectively. Calibrating the values of k this way ensures that these two sectors earn some positive resource rent even before a full rationalization of the mackerel sector.

The base-year quantity of a factor of production (labor or capital) in an industry was 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 a fishing industry in this study, this factor income excludes resource rent. Calibrating the quantity of a factor for the fishing industry in this manner means that the market price of the factor is 1 million KRW in the base year. Next, the base-year level of effort in the fishing industry is determined simply by adding up the base-year quantities of labor and capital, as calibrated above. Although the large purse seine accounts for a large portion (86%) of the mackerel catch, the gear type catches other species as well. So we separated effort (labor and capital) for mackerel harvest based on the ratio of the total revenue from the large purse seine sector accounted for by mackerel harvest. For simplicity, we specified the technology for non-mackerel fishing sector based on the weighted average of the technologies (expenditures on inputs) of the vessels with different gear types catching all the other species.

The elasticity of substitution in the effort function was set to 0.61 for the two fish harvesting sectors. Given the base-year level of effort, the elasticity of substitution, and the share parameter in the effort function [Equation (2)], the shift parameter was calibrated. This yielded the unit cost of effort (C) in Equation (3) 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. Similarly, the unit of output is calibrated such that one unit of output is sold at 1 million KRW in the base year. The catchability parameter (d) was calibrated given the stock elasticities and 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 shift parameters in the CES production function for non-fishing industries, the CES Armington function, and the CET function used to determine the sales of a good to the local market and ROW were calibrated in a standard way. In other words, the shift parameters in these functions were calibrated given the elasticity values and base-year levels of the variables in the functions.

To calibrate the parameters in the logistic growth function [Equation (11)], this study used the harvest data from KOSIS (2022). For Busan's mackerel and non-mackerel fisheries, we estimated intrinsic growth rate, biomass, and carrying capacity following Hong and Kim (2021) who used the Bayesian state-space (BSS) method (Froese et al. 2017). Estimates of the stock level indicate that it fluctuated wildly during the past 10 years or so. Furthermore, the estimates of the growth rate and the carrying capacity are subject to a high degree of uncertainty evidenced by wide confidence intervals. Therefore, we assumed that the bioeconomic system is in a steady state in the base year. To calibrate the growth model for the steady-state assumption, we first calculated the *average* stock level over the most recent five years (2018-2022) for which the estimates are available. Next, given the base-year level of the carrying capacity along with the average biomass, we calibrated the intrinsic growth rate so that the bioeconomic system is on the steady-state path in the base year. When conducting the sensitivity analysis where the ratio of biomass to carrying capacity varies, we fixed the growth rate thus calibrated and adjusted the levels of biomass and the carrying capacity so that the system is on a steady state path in the base year. For a list of the values of the parameters (elasticities) used in this study and their sources, see Appendix B, Table B.3.

Appendix D Solving the Dynamic Model

To derive the time paths of the optimal harvest level under rationalized mackerel fishery, we specified a deterministic, discrete-time finite-horizon dynamic programming problem with continuous state (biomass) and control (harvest level) variables. In the dynamic model, the harvest levels are determined such that the present value of the profits is maximized over time with the dynamic opportunity cost of the resource considered. The model set up below constitutes a non-linear programming problem. We solved the model using GAMS (General Algebraic Modeling System) NLP (non-linear programming) CONOPT4 solver (Cai 2019). The terminal period is set at the 100th year.

Specifically, we maximize

Max $OBJ = \sum_{t}^{TL} \frac{1}{(1+d)^t} \left(PV_t H_t - C_t E_t\right)$

subject to

Initial condition

$N_{TF} = N_0$ (D1)

The level of stock in the first period equals its base-year level.

Fish harvest function

$H_t = dE_t^f N_t^g,$ (D2)

Relationship between fish harvests in KRW and tons

$HARV_t = \tau \cdot H_t,$ (D3)

Fish growth function

$N_{t+1} = N_t + \gamma N_t \left(1 - \frac{N_t}{KC}\right) - HARV_t,$ (D4)

Last period condition

$HARV_{TL} = N_{TL} + \gamma N_{TL} \left(1 - \frac{N_{TL}}{KC}\right)$ (D5)

The level of harvest in the last period equals the growth of the fish stock.

All the other general equilibrium equations defined for each period (year) (D6)

The following describes the parameters and variables.

t	time period
τ	unit-changing parameter
TF	first period
TL	last period (100th year)

d	discount rate (=0.045)
PV_t	price of value-added in period t
H_t	fish production in period t measured such that one unit of fish sells for one million KRW
f	effort elasticity
g	stock elasticity
$HARV_t$	fish harvest in period t in actual weight (tons)
C_t	unit cost of fish harvesting effort in period t
E_t	effort in period t
N_t	biomass in period t
γ	Intrinsic growth rate
KC	carrying capacity