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# Web Appendices

## Appendix A

This appendix presents the variables, parameters, and equations used in Model 3 of the KIB CGE model. In this appendix, *i* and *j* denote production sectors (activities); *fs* and *nfs* denote, respectively, fish harvesting sectors and non-fish harvesting sectors; *n* denotes total number of production sectors; *k* and *l* denote the total numbers of fish harvesting and non-fish harvesting sectors, respectively, where $k + l = n$; *c* and *d* denote commodities; *m* denotes total number of commodities; *h* and *hh* denote household types; *s* denotes total number of household types. Factor market equilibrium conditions for all eight model variants are shown in Table A.1 below.

### A.1 List of Endogenous Variables

| | |
|---|---|
| $CFG_c$ | Federal government demand for commodity *c* |
| $C_{fs}$ | Unit cost of fish harvesting effort |
| $CSG_c$ | State and local 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 | Enterprise savings |
| ER | Exchange rate |
| FEDGDTOT | Federal government expenditure on commodities |
| FGEXP | Total federal government expenditure |
| FGREV | Federal government revenue |
| FSAV | External savings |
| GRP | Gross regional product at market prices |
| GSF | Federal government savings |
| GSS | State and local 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 |
| R | Market return to capital |
| SGEXP | Total state and local government expenditures |
| SGREV | State and local government revenue |
| STGDTOT | State government expenditures on commodities |
| TRAFS | Federal transfers to state 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 | Total capital income |
| YKK | Capital income after leakage, federal and state/local tax, and enterprise savings |
| YL | Total labor income |
| YLL | Labor income after leakage and social security tax payment |
| $Z_c$ | Output of commodity *c* |

## A.2 List of Exogenous Variables

| | |
|---|---|
| $FTR_h$ | Federal government transfers to household *h* |
| $REMH_h$ | Remittances from the rest of the world |
| $STR_h$ | State and local government transfers to household *h* |
| $PWE_i$ | World price of exported good *i* |
| $PWM_i$ | World price of imported good *i* |

## A.3 List of Parameters

<u>Import Demand</u>

| | |
|---|---|
| $A_c^C$ | Armington function shift parameter |
| $\delta_c$ | Armington function share parameter |
| $\rho_c$ | Armington function exponent |
| $\upsilon_c$ | Elasticity of substitution between imports and local goods |

<u>Production</u>

| | |
|---|---|
| $\Delta_{i,c}$ | Row-sum normalized make matrix |
| $a_{c,i}$ | Technical coefficients |

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| | |
|---|---|
| $\Phi_i$ | Value-added function shift parameter for non-fishing industries |
| $\alpha_i$ | Value-added function share parameter for non-fishing industries |
| $\sigma_i$ | Value-added function exponent for non-fishing industries |
| $\Psi_{fs}$ | Effort function shift parameter for fishing industries |
| $\alpha_{fs}$ | Effort function share parameter for fishing industries |
| $\sigma_{fs}$ | Effort function exponent for fishing industries |
| $\theta_L$ | Share of resource rent received by labor |
| $\theta_K$ | 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 |
| $v_{fs}$ | Parameter measuring the degree of openness of the fishery |

Export Supply

| | |
|---|---|
| $A_c^T$ | CET function shift parameter |
| $\varphi_c$ | CET function share parameter |
| $\theta_c$ | CET function exponent |
| $\Lambda_c$ | Elasticity of transformation |

Consumption

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

Budget of Household

| | |
|---|---|
| $ee_h$ | Capital income share to household *h* |
| $ll_h$ | Labor income share to household *h* |
| wleakr | Labor income leakage rate |
| rleakr | Capital income leakage rate |
| sstr | Social security tax rate |
| esrate | Enterprise savings rate |
| $MPS_h$ | Marginal propensity to save for household *h* |
| $trst_h$ | State and local income tax rate for household *h* |
| $trfed_h$ | Federal income tax rate for household *h* |

Budgets of Governments

| | |
|---|---|
| sibt | State and local govt. indirect business tax share |
| fibt | Federal govt. indirect business tax share |
| $stgles_c$ | State and local govt. demand commodity share |
| $fedgles_c$ | Federal govt. demand commodity share |

Capital and Investment

| | |
|---|---|
| ktrfed | Federal tax rate on capital |

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ktrst State and local tax rate on capital
$invrat_c$ investment ratio for commodity *c*

## A.4 List of Equations

### Model Closure

The following variables are fixed at their base-year levels: ER, FEDGDTOT, $N_{fs}$, ITOT, LTOT, KTOT, STGDTOT.

### Prices

Definition of domestic import prices:

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

Definition of domestic export prices:

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

Definition of composite good prices:

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

Definition of domestic sales prices:

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

Definition of domestic industry prices:

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

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:

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

Unit cost of effort function:

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

Effort demand function (regulated open access fishery)

$$\frac{v_{fs} PV_{fs} X_{fs}}{E_{fs}} = C_{fs} \quad (9)$$

Effort demand function (rationalized fishery)

$$\frac{f_{fs} PV_{fs} X_{fs}}{E_{fs}} = C_{fs} \quad (9)'$$

Labor demand function for fish harvesting:

$$L_{fs} = \left( \frac{E_{fs}}{\Psi_{fs}} \right) \left[ \frac{(1-\alpha_{fs}) \Psi_{fs} C_{fs}}{W} \right]^{\sigma_{fs}} \quad (10)$$

Capital demand function for fish harvesting:

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

<u>Non-fishing industries</u>

Unit cost function:

$$UC_{nfs} = \frac{1}{\Phi_{nfs}} [\alpha_{nfs}{}^{\sigma_{nfs}} R^{(1-\sigma_{nfs})} + (1-\alpha_{nfs})^{\sigma_{nfs}} W^{(1-\sigma_{nfs})}]^{\frac{1}{(1-\sigma_{nfs})}} \quad (11)$$

Labor demand function:

$$L_{nfs} = \left( \frac{X_{nfs}}{\Phi_{nfs}} \right) \left[ \frac{(1-\alpha_{nfs}) \Phi_{nfs} UC_{nfs}}{W} \right]^{\sigma_{nfs}} \quad (12)$$

Capital demand function:

$$K_{nfs} = \left( \frac{X_{nfs}}{\Phi_{nfs}} \right) \left[ \frac{\alpha_{nfs} \Phi_{nfs} UC_{nfs}}{R} \right]^{\sigma_{nfs}} \quad (13)$$

Intermediate demand of sector i for commodity c:

$$ND_{c,i} = a_{c,i} X_i \quad (14)$$

Definition of domestic commodity output:

$$Z_c = \sum_i \Delta_{i,c} X_i \quad (15)$$

Zero profit condition for non-fishing industries:

$$PV_{nfs} X_{nfs} = W \cdot L_{nfs} + R \cdot K_{nfs} \tag{16}$$

**Household Demand**

Household consumption demand:

$$HC_{c,h} = \frac{\beta_{c,h} HEXP_h}{PQ_c^{\gamma_h} \sum_c \beta_{c,h} PQ_c^{(1-\gamma_h)}} \tag{17}$$

**Income Block**

Total labor income:

$$YL = \sum_i W \cdot L_i + \sum_{fs} \theta_L (1 - v_{fs}) PV_{fs} X_{fs} \tag{18}$$

(regulated open access)

$$YL = \sum_i W \cdot L_i + \sum_{fs} \theta_L (1 - f_{fs}) PV_{fs} X_{fs} \tag{18'}$$

(rationalized fishery)

Total capital income:

$$YK = \sum_i R \cdot K_i + \sum_{fs} \theta_K (1 - v_{fs}) PV_{fs} X_{fs} \tag{19}$$

(regulated open access)

$$YK = \sum_i R \cdot K_i + \sum_{fs} \theta_K (1 - f_{fs}) PV_{fs} X_{fs} \tag{19'}$$

(rationalized fishery)

Labor income after leakage and social security tax payment:

$$YLL = (1 - wleakr - sstr) YL \tag{20}$$

Capital income after leakage, federal and state/local tax, and enterprise savings:

$$YKK = (1 - rleakr - ktrfed - ktrst - esrate) YK \tag{21}$$

Household factor income:

$$YH_h = ll_h YLL + ee_h YKK \tag{22}$$

Total household income:

$$TYH_h = YH_h + FTR_h + STR_h + REMH_h \tag{23}$$

Household expenditure:

$$HEXP_h = (1 - trfed_h - trst_h - MPS_h)TYH_h \tag{24}$$

**Federal and State & Local Governments**

Federal government revenue:

$$FGREV = fibt\sum_i itr_i PX_i X_i + (ktrfed)YK + \sum_h (trfed_h)TYH_h + (sstr)YL \tag{25}$$

Federal government expenditure:

$$FGEXP = \sum_c (PQ_c)CFG_c + TRAFS + \sum_h FTR_h \tag{26}$$

Federal government demand for commodities:

$$PQ_c CFG_c = (fedgles_c)FEDGDTOT \tag{27}$$

State and local government revenue:

$$SGREV = sibt\sum_i itr_i PX_i X_i + (ktrst)YK + \sum_h (trst_h)TYH_h + TRAFS \tag{28}$$

State and local government expenditure:

$$SGEXP = \sum_c (PQ_c)CSG_c + \sum_h STR_h \tag{29}$$

State and local government demand for commodities:

$$PQ_c CSG_c = (stgles_c)STGDTOT \tag{30}$$

Federal government transfer to state and local government:

$$TRAFS = (fsrat)FGREV \tag{31}$$

**Savings and Investment**

Household savings:

$$HSAV_h = (MPS_h)TYH_h \tag{32}$$

Enterprise savings:

$$ENTSAV = (esrate)YK \tag{33}$$

Federal government savings:

$$GSF = FGREV - FGEXP \tag{34}$$

State and local government savings:

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$$GSS = SGREV - SGEXP \tag{35}$$

External savings:

$$FSAV = \sum_c PM_c M_c - \sum_c PE_c E_c + (wleakr)YL + (rleakr)YK - \sum_h REMH_h \tag{36}$$

Total savings:

$$TSAV = \sum_h HSAV_h + ENTSAV + GSF + GSS + (ER)FSAV \tag{37}$$

Investment by sector of origin:

$$ID_c = \frac{(invrat_c)\, ITOT}{PQ_c} \tag{38}$$

**Exports and Imports**

Supply aggregation function:

$$Z_c = A_c^T [\varphi_c E_c^{\theta_c} + (1-\varphi_c) D_c^{\theta_c}]^{\frac{1}{\theta_c}} \tag{39}$$

Export supply function:

$$E_c = \left(\frac{PE_c}{PD_c}\right)^{\Lambda_c} \left(\frac{1-\varphi_c}{\varphi_c}\right)^{\Lambda_c} D_c \tag{40}$$

Demand aggregation function:

$$Q_c = A_c^C [\delta_c M_c^{-\rho_c} + (1-\delta_c) D_c^{-\rho_c}]^{-\frac{1}{\rho_c}} \tag{41}$$

Import demand function:

$$M_c = \left(\frac{PD_c}{PM_c}\right)^{\upsilon_c} \left(\frac{\delta_c}{1-\delta_c}\right)^{\upsilon_c} D_c \tag{42}$$

**Equilibrium Conditions**

Goods market equilibrium:

$$Q_c = \sum_h HC_{c,h} + \sum_i ND_{c,i} + ID_c + CFG_c + CSG_c \tag{43}$$

Labor market equilibrium condition:

$$LTOT = \sum_i L_i \tag{44}$$

Capital market equilibrium condition:

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$$KTOT = \sum_i K_i \tag{45}$$

**Gross Regional Product**

Gross regional product at market prices:

$$GRP = \sum_i [PV_i X_i + itr_i PX_i X_i] \tag{46}$$

Real gross regional product:

$$RGRP = \sum_c \left[ \sum_h HC_{c,h} + ID_c + CFG_c + CSG_c + E_c - M_c \right] \tag{47}$$

The model has a total of (2*n* + 7*k* + 4*l* + 13*m* + 4*s* + *m*·*s* + *m*·*n* + 24) endogenous variables and the same number of equations, where *n* = number of industries; *k* and *l* denote the total numbers of fishing and non-fishing sectors, respectively (*k* + *l* = *n*); *m* = number of commodities, s = number of household types. Note: there is only one aggregate household in the KIB CGE model (s = 1).

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**Table A.1 Equilibrium conditions in factor markets**

<table>
<tr><th></th><th>Labor market</th><th>Capital market</th><th>Variables determined endogenously within the model</th></tr>
<tr><td>Model 1</td><td rowspan="4">$\sum_i L_i = \overline{LTOT}$</td><td>$K_{fs} = \overline{K_{fs}}$<br>$\sum_{nfs} K_{nfs} = \overline{KTN}$</td><td>W, $R_{fs}$, RN, $L_i$, $K_{nfs}$</td></tr>
<tr><td>Model 2</td><td>$\sum_{fs} K_{fs} = \overline{KTF}$<br>$\sum_{nfs} K_{nfs} = \overline{KTN}$</td><td>W, $K_i$, RF, RN, $L_i$</td></tr>
<tr><td>Model 3</td><td>$\sum_i K_i = \overline{KTOT}$</td><td>W, $K_i$, R, $L_i$, KTF, KTN</td></tr>
<tr><td>Model 4</td><td>$R = \bar{R}$</td><td>W, $K_i$, $L_i$, KTF, KTN, KTOT</td></tr>
<tr><td>Model 5</td><td rowspan="4">$W = \bar{W}$</td><td>Same as Model 1 conditions.</td><td>$R_{fs}$, RN, $L_i$, $K_{nfs}$, LTOT</td></tr>
<tr><td>Model 6</td><td>Same as Model 2 conditions.</td><td>$K_i$, RF, RN, $L_i$,LTOT</td></tr>
<tr><td>Model 7</td><td>Same as Model 3 conditions.</td><td>$K_i$, R, $L_i$, KTF, KTN, LTOT</td></tr>
<tr><td>Model 8</td><td>Same as Model 4 conditions.</td><td>$K_i$, $L_i$, KTF, KTN,KTOT, LTOT</td></tr>
</table>

<u>Variable Names for Table A.1</u>

$K_{fs}$ : capital in fish harvesting sectors
$K_{nfs}$ : capital in non-fish harvesting sectors
KTF : total capital stock in fish harvesting sectors, $\overline{KTF}$ when fixed
KTN : total capital stock in all the non-fish harvesting sectors, $\overline{KTN}$ when fixed
KTOT : total capital stock in the economy, $\overline{KTOT}$ when fixed
$L_i$ : labor in sector *i*
LTOT : total labor stock in the economy, $\overline{LTOT}$ when fixed
R : economy-wide return to capital, $\bar{R}$ (return to capital in the rest of world) when fixed
$R_{fs}$ : return to capital in fish harvesting sectors
RF : one single return to capital for fish harvesting sectors
RN : one single return to capital for non-fishing sectors
W : economy-wide wage rate, $\bar{W}$ (wage rate in the rest of world) when fixed

## Appendix B

**Table B.1 Social Accounting Matrix for the KIB CGE Model**

| | Activity | Commodity | Value-added | Households | State & Local Govt. | Federal Govt. | Savings-Investment | Rest of the World |
|---|---|---|---|---|---|---|---|---|
| **Activity** | | Gross Output | | | | | | |
| **Commodity** | Intermediate Inputs | | | Household Purchase | S&L Govt. Purchase | Fed. Govt. Purchase | Investment Demand | Exports |
| **Value-added** | Value-added | | | | | | | |
| **Households** | | | Factor Income | Inter-HH Transfers | S&L Govt. Transfers to HHs | Fed. Govt. Transfers to HHs | HH Investment Income | |
| **State & Local Govt.** | | | S&L Govt. Factor Taxes + Indirect Business Tax | Household Taxes | S&L Govt. Transfers | Fed. Govt. Transfer | S&L Govt. Investment Income | |
| **Federal Govt.** | | | Social Security Tax + Indirect Business Tax | Personal Income Tax | | | Fed. Govt. Investment Income | |
| **Savings-Investment** | | | Business Savings | Household Savings | S&L Govt. Savings | Fed. Govt. Savings | | External Savings |
| **Rest of the World** | | Imports | Factor Income Leakage | HH Income Leakage | S&L Govt. Leakage | Fed. Govt. Leakage | | |

**Table B.2 Sector Aggregation Scheme for KIB CGE Model**

| IMPLAN Sectors (536 Industries) | Sectors in Kodiak CGE Model |
|---|---|
| Sector 17 (Replaced with estimated data) | Trawl gear sector |
| Sector 17 (Replaced with estimated data) | Non-trawl gear sector |
| Sector 93 (Replaced with estimated data) | Processing fish from Trawl gear sector |
| Sector 93 (Replaced with estimated data) | Processing fish from Non-trawl gear sector |
| Sectors 1-16, 18-40 | Agriculture and Mining |
| Sectors 41-51, 519, 522 and 525 | Utilities |
| Sectors 52-64 | Construction |
| Sectors 65-92 and 94-105 | Other Food Processing |
| Sectors 106-394 | Other Manufacturing |
| Sector 395 | Wholesale Trade |
| Sectors 396-407 | Retail Trade |
| Sectors 408-416 | Transportation |
| Sectors 417-440, and 442-517 | All Other Services |
| Sectors 441, and 527-530 | Miscellaneous |
| Sectors 521, 523-524, 526, and 531-534 | State and Local Government Services |
| Sectors 518, 520, and 535-536 | Federal Government Services |

**Table B.3 Parameter Values used in the KIB CGE Model**

| Elasticities and Parameters | Value |
|---|---|
| Elasticity of Effort in Harvest Function [a] | |
| Trawl fishing | 0.415 |
| Non-trawl fishing | 0.296 |
| Elasticity of Stock in Harvest Function [a] | |
| Trawl fishing | 0.585 |
| Non-trawl fishing | 0.704 |
| Degree of openness in fishery (pre-rationalization) [a] | |
| Trawl fishing | 0.869 |
| Non-trawl fishing | 0.739 |
| Elasticity of Substitution in Effort Function [b] | |
| Trawl fishing and Non-trawl fishing | 0.61 |
| Elasticity of Substitution in Production [b] | |
| Processing fish from Trawl and Non-trawl harvesting sectors, Agriculture and Mining | 0.61 |
| All the other industries | 0.80 |
| Elasticity of Substitution in Consumption [c] | 1.125 |
| Elasticity of Substitution between Imports and Local Goods [d] | |
| Trawl fishing, Non-trawl fishing, Agriculture and Mining | 1.42 |
| Seafood processing | 0.31 |
| Construction | 3.15 |
| Other Food Manufacturing, Other Manufacturing | 3.55 |
| All the other commodities | 2.00 |
| Elasticity of Transformation in Production: Domestic Goods and Exports [e] | |
| Trawl fishing, Non-trawl harvesting, Agriculture and Mining | 3.9 |
| Seafood processing, Construction, Other Food Manufacturing, Other Manufacturing | 2.9 |
| All the other commodities | 0.7 |
| Before-policy size of population of study region [f] | 13,101 |

Source:
a Author's estimation
b The elasticity values are based on de Melo and Tarr (1992, p. 232).
c The elasticity of substitution for the aggregate household's consumption at the average value of the elasticities for low- and high-income households from Shoven and Whalley (1984, p. 1011).
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 https://www.census.gov/quickfacts/fact/table/kodiakislandboroughalaska/PST045221

## Appendix C Parameterization and calibration

### C.1 Calibrating stock elasticity

For the stock elasticity parameter value ($g$) in Equation (1), some previous studies simply use an assumed value of the elasticity. For example, Manning et al. (2018) assumes an elasticity value of 0.4 for an artisanal fishery in Honduras. Other studies estimate the harvest function econometrically. Finnoff et al. (2007), for instance, estimates the stock elasticity parameter to be 0.21 for Alaska pollock fishery. Apriesnig (2017) estimates the harvest function for Lake Erie yellow perch fishery in Ohio, and imputes the stock elasticity value of 0.237 assuming that the harvest function is CRS. Similarly, Gilliland et al. (2019) estimates the harvest function for a local area's fishery in the Philippines (El Nido on the island of Palawan), and imputes a fish stock elasticity value of 0.13 assuming a CRS fish harvest function.

An ideal way of specifying the stock elasticity is to estimate econometrically the elasticity using time series data for harvest, fishing effort, and biomass data, as is done in some of the studies mentioned above. The present study does not rely on econometric estimation of the stock elasticity due to data limitations. First, the GOA groundfish trawl fishery is not a single-species fishery but a multi-species fishery. Although the time series data for the fishing effort (number of vessels) and the biomass are available for some species (e.g., pollock), similar data for other species are not available. Second, even if the data for these variables were available for all species, aggregating the data across different species could be problematic.

Instead, this study uses the relationship between the stock elasticity and the quota share lease rate that is obtained from, or estimated based on, a fishery (or species) similar to the GOA groundfish trawl fishery. For Trawl sector, this study uses a quota share lease rate (0.331) estimated based on a study (Seung and Ianelli 2016 ) of another Alaska fishery, the Bering Sea and Aleutian Islands (BSAI) pollock fishery, which was rationalized in 1998 (American Fisheries Act, 1998). For Non-trawl sector, this study simply assumes a quota share lease rate of 0.5, following "Wilen's rule of thumb" (e.g., Homans and Wilen 2005; Asche et al. 2009). More specifically, this study follows the procedures below to calibrate the elasticity values.

Assume that the fishery for a species is fully rationalized, resource rent exists, and the quota lease and sales markets for the species function well. Then the quota share lease rate ($q$) can be defined as the resource rent divided by the ex-vessel revenue:

$$q = \frac{RENT}{PX \cdot H} \ , \tag{C.1}$$

where $RENT$ is the resource rent, $PX$ is the ex-vessel price of the harvested fish, and $H$ is the harvest level. The resource rent can be computed as:

$$RENT \ = g \cdot PV \cdot H \ , \tag{C.2}$$

where $g$ is the stock elasticity, and $PV$ is the value-added per unit of harvest (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).

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From Equations (C.1) and (C.2), the stock elasticity is calibrated as

$$g = \frac{PX}{PV} q \quad . \tag{C.3}$$

Thus, given a value of the quota share lease rate ($q$) along with the values of $PX$ and $PV$, the stock elasticity for Trawl sector can be obtained. An early study (Seung and Ianelli 2016) uses a quota share lease rate of 0.5 for Alaska pollock provided by Felthoven (2014)[1]. While the study (Seung and Ianelli 2016) assumes a discount rate of 10% as in Felthoven (2014), the present study uses a more conservative discount rate of 7% that results in a value of $q$ of 0.331. Data used in Seung and Ianelli (2016) indicates that the ratio of $PX$ to $PV$ for the pollock fishery is 1.764 (= 1/0.567). Given these values, the stock elasticity value of 0.585 is obtained using Equation (C.3). Reliance on Seung and Ianelli (2016) is reasonable because the largest portion of the harvest by the GOA groundfish trawlers is accounted for by the same species (pollock) as in Seung and Ianelli (2016).

The other fish harvesting sector (Non-trawl sector) in the KIB CGE model also catches a mix of different species including salmon, halibut, Pacific cod, and sablefish. North Pacific Fishery Management Council and National Marine Fisheries Service (2016, Tables 2.6-9 and 2.6-10, Pages 260-261) reports the quota share prices for the halibut and sablefish by regulatory area. Using this information, and assuming the same discount rate (7%), the quota share lease rates for halibut and sablefish, respectively, are estimated to be 0.446 [average of International Pacific Halibut Commission (IPHC) halibut management areas 3A and 2C] and 0.288 (for Sablefish IFQ regulatory area Central GOA), for the base year (2014).

However, there are other major species caught in Non-trawl sector. Salmon, in particular, accounts for a large share of the total ex-vessel revenue of the sector (45%). For this species, the quota share lease rate is not available. This makes it difficult to estimate the quota share lease rate for the whole Non-trawl sector. Therefore, this study assumes a quota share lease rate of 0.5 [following "Wilen's rule of thumb" as in Homans and Wilen (2005) and Asche et al. (2009)] for the whole Non-trawl sector. Base year data for the KIB CGE model indicates that the ratio of $PX$ to $PV$ for Non-trawl sector is 1.408 (= 1 / 0.71). Plugging these three values into Equation (C.3) yields a stock elasticity value of 0.704. A caveat is that the value of $PV$ is from a fishery (KIB's Non-trawl fishery) that is not fully rationalized, but is a mix of both rationalized (halibut and sablefish) and open access (e.g., salmon) fisheries. Since the value of $PV$ that would be obtained if the fishery were fully rationalized will be higher than its pre-rationalization value, using the pre-rationalization value of $PV$ (instead of its post-rationalization value) for Non-trawl sector is likely to overestimate the stock elasticity to some extent.

The calibrated values of the stock elasticity ($g$) for the two harvesting sectors (0.585 for Trawl sector and 0.704 for Non-trawl sector) are used in Equation (1) above. The values of the effort

[1] In Seung and Ianelli (2016), the base-year quota share lease rate of 0.5 for pollock is derived as follows. Conversations with seafood industry participants indicate that pollock quota has been selling at about $1,900 per metric ton. It is assumed that the discount rate is 10%, which implies a perpetuity (resource rent) of $190 per metric ton. In 2012, ex-vessel prices were about $0.17/lb or $375 per metric ton. This leads to a quota share lease rate that is approximately 0.5 of the ex-vessel price (Felthoven 2014).

elasticity (*f*) in the equation are derived from the calibrated values of the stock elasticity. That is, $f$ = 1-0.585 = 0.415 for Trawl sector and $f$ = 1-0.704 = 0.296 for Non-trawl sector.

## C.2 Calibrating *v* in Equation (7)

In the present study, most species in the Trawl sector are under regulated open-access regimes. One exception is rockfish which are under a catch-share program where fishing rights are granted to participants in the fishery. Similarly, the Non-trawl sector is a mix of rationalized (halibut and sablefish) and regulated open access (all other species) fisheries. Furthermore, there are other factors that make the fisheries in the two sectors non-pure open access, e.g., the non-rationalized species in the sectors are managed under some regulations (e.g., license limitation).

Using Equation (7), Equation (8) can be expressed as:

$$RENT = (1 - v) \cdot PV \cdot H \ , \qquad \text{(C.4)}$$

This study uses Equation (C.4) to calibrate the values of *v* for the two fishing sectors under regulated open access, as detailed below.

For calibration purpose in this section, this equation is defined to describe specifically the *sector-level* relationship among the variables *(RENT*, *PV*, and *H*) and the parameter (*v*). Therefore, the variables and the parameter do not have any subscripts or superscripts denoting any individual species caught by a fishing sector.

The resource rent *for an individual species* in a fishing sector is defined as:

$$RENT_{sp} = \left(1 - v_{sp}\right) \cdot PV_{sp} \cdot H_{sp} \ , \qquad \text{(C.5)}$$

where *sp* denotes species. Since the sum of the resource rents from harvests of all species in a fishing sector equals the total rent for the whole fishing sector,

$$RENT = (1 - v) \cdot PV \cdot H = \sum_{sp=1}^{S} RENT_{sp} = \sum_{sp=1}^{S} \left(1 - v_{sp}\right) \cdot PV_{sp} \cdot H_{sp} \ , \qquad \text{(C.6)}$$

where *S* denotes the number of species caught in a fishery.

In the case of Trawl sector, $v_{sp} = f_{sp}$ if *sp* = rockfish and $v_{sp} = 1$ for all the other species. Therefore, for Trawl sector,

$$(1 - v) \cdot PV \cdot H = (1 - v_{rock}) \cdot PV_{rock} \cdot H_{rock} \ , \qquad \text{(C.7)}$$

where subscript "rock" denote rockfish. Equation (C.7) states that only rockfish harvest generates resource rent in Trawl sector before full rationalization of the sector. Solving this equation for the sector-level degree of openness parameter (*v)*,

$$v = 1 - \frac{(1 - v_{rock}) \cdot PV_{rock} \cdot H_{rock}}{PV \cdot H} \ . \qquad \text{(C.8)}$$

Since there is no information on the quota share lease rate (and therefore, the stock elasticity) available for rockfish, the stock elasticity for rockfish is assumed to equal the stock elasticity for the whole Trawl sector elasticity ($g_{rock}$ = 0.585). It follows that $f_{rock} = v_{rock}$ = 0.415. Then using the values of the value added prices (*PV* and $PV_{rock}$) and harvest levels (*H* and $H_{rock}$) from Seung et al. (2020) along with the value of $v_{rock}$ above, *v* (the sector-level degree of openness parameter for Trawl sector) is calibrated to be 0.966.

To calibrate the degree of openness parameter for Non-trawl sector, this study first calculates the stock elasticities for halibut and sablefish based on the quota share lease rates estimated in Section C.1 above (0.446 for halibut and 0.288 for sablefish). Given (i) the quota share lease rates above and (ii) the values *PX*s and *PV*s for the two species (Seung et al. 2020), this study uses Equation (C.3) to compute the stock elasticities for the two species. The stock elasticities thus estimated are 0.371 and 0.594, respectively. Then, it follows that $f_{hal} = v_{hal} = (1\text{-}g_{hal})$ and $f_{sab} = h_{sab} = (1\text{-}g_{sab})$ where *hal* and *sab* denote halibut and sablefish, respectively.

Next, the relationship among the sector- and species-level variables and parameters, similar to Equation (C.7), is given as:

$$(1-v)\cdot PV\cdot H = (1-v_{hal})\cdot PV_{hal}\cdot H_{hal} + (1-v_{sab})\cdot PV_{sab}\cdot H_{sab} \quad . \qquad \text{(C.9)}$$

Solving this equation for *v*,

$$v = 1 - \frac{(1-v_{hal})\cdot PV_{hal}\cdot H_{hal} + (1-v_{sab})\cdot PV_{sab}\cdot H_{sab}}{PV\cdot H} \quad . \qquad \text{(C.10)}$$

The sector-level degree of openness parameter for Non-trawl sector thus calibrated is 0.821.

Note that when calibrating the values of the degree of openness parameter for the two sectors (*v*; 0.966 and 0.821), it is assumed that the non-rationalized species (i.e., all the species excluding rockfish, halibut, and sablefish) are under pure open access and therefore, do not yield any resource rent. But because the harvests of the non-rationalized species are under some regulations (e.g., license limitation), they may generate some resource rent. This means that the values for the degree of openness parameter above (0.966 and 0.821) may be overestimated to some degree, or equivalently, that the base-year resource rents generated for the two sectors are underestimated to some degree. To address this problem, the values of *v* calibrated above are adjusted downward albeit in a rather arbitrary manner. This study assumes that the new values are 10% smaller than the calibrated values above, and are computed to be 0.869 and 0.739, respectively, for Trawl and Non-trawl sectors.

### C.3 Calibrating other parameters

In the base year, the quantity of a factor of production (labor or capital) in an industry is calibrated to equal its base-year factor income divided for convenience by $1 million, which includes only that portion of the factor income that reflects its opportunity cost (the market return to the factor). Therefore, for a fishing industry, this factor income does not include the resource rent distributed to the factor in the year. Calibrating the quantity of a factor for a fishing industry this way means that the market price of the factor is $1 million in the base year. Then, the base-year level of effort in the fishing industry is determined simply by the sum of the base-year quantities of labor and capital thus calibrated. Given the base-year level of effort, the elasticity of substitution, and the share parameter in Equation (2), the shift parameter is calibrated using the equation. This yields the unit cost of effort (C) in Equation (3) which equals $1 million in the base year. This means that the unit of effort is calibrated such that one unit of effort costs $1 million. Similarly, the unit of output is calibrated such that one unit of output is sold at $1 million in the base year.

The catchability parameter (*d*) is calibrated once the values of the stock elasticities are specified. The calibrated values of the catchability parameter are 0.0044 (Trawl sector) and 0.0017 (Non-trawl sector), respectively. The elasticity of substitution in the effort function is set to 0.61 for the two fish harvesting sectors. For the list of the values of the parameters (elasticities) used in the baseline simulation in this study and their sources, see Appendix B Table B.3.

Other parameters, such as the shift parameters in the CES effort function, 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 are calibrated in a standard way. That is, the shift parameters in these functions are calibrated given the elasticity values and the base-year levels of the variables in the functions.

## Appendix D Sensitivity analyses

### D.1 Descriptions of sensitivity analyses

There are three parameters (elasticities) that are important to determining fish production in this study. They are the catchability parameter (*d*) in the fish harvest function, the stock elasticity (*g*) in the function, and the elasticity of substitution ($\sigma$) in the effort function. Thus, in addition to simulating the shift to rationalization using the calibrated values of the parameters above (baseline simulation), this study implements sensitivity tests for these parameters since these parameters are calibrated or assumed based on previous studies.

Rationalization may enhance fishing efficiency through two pathways. First, efficiency may improve through a reduction in the level of effort needed to catch a given amount of fish. Second, efficiency may improve through an increase in the catchability. Apriesnig (2017) explores how the effects of an ITQ system vary when the catchability improves over a range from 0% to 100%. Since there is no evidence concerning how much Trawl sector catchability will rise due to rationalization, the present study first simulates the transition to rationalization assuming catchability rises by 20% (baseline simulation), which is a rather arbitrary assumption. For the sensitivity analysis in this section, this assumption is relaxed to scrutinize how sensitive the results are to different values (0%, 10%, and 30%) of the percentage change in the catchability parameter.

For the stock elasticity, this study simulates the shift to rationalization with the original elasticity (0.585) for Trawl sector in the baseline simulation. In this section, a sensitivity analysis is conducted by running the model using two alternative values of the elasticity that are 10% lower (0.527) and 10% higher (0.644) than the original elasticity (0.585). Furthermore, this study carries out a sensitivity test for the elasticity of substitution in the effort function where the model is run with values that are 10% lower (0.55) and 10% higher (0.67) than its baseline value (0.61).[2]

When fishery managers implement a rationalization policy for a fishery, they often keep the pre-rationalization level of its TAC. In a sensitivity analysis, the regime shift is simulated assuming that the catch level (or TAC) is fixed at the pre-rationalization level, allowing the catchability parameter to increase endogenously to support this catch level. This means the resulting increase in the parameter due to the rationalization is just enough to maintain the pre-rationalization catch level. Table D.1 presents the parameter values used for sensitivity analyses.[3]

## D.2 Results from sensitivity analyses

*Sensitivity to stock elasticity*

To conduct a sensitivity analysis for the stock elasticity, this study simulates the regime shift with the elasticity values that are 10% lower (0.527) and 10% higher (0.644), respectively, than the original (medium) elasticity (0.585) for Trawl sector. Results illustrate that the larger the elasticity, the larger the reduction in the level of effort across all model variants (Figure D.1). When catch increases (Models 1 and 5), the larger the elasticity, the smaller the increase in catch (Figure D.2). On the other hand, when catch decreases, it decreases by larger percentages with higher elasticity values (Models 2, 3, 6, and 7) when factors are relatively mobile, whereas this is not necessarily the case with Models 4 and 8.

With the lower (higher) stock elasticity, resource rent is consistently smaller (larger) than with the original elasticity across all model variants because a lower (higher) stock elasticity means that the contribution of the stock to rent is smaller (larger) (Figure D.3). Changes in RVA exhibit different patterns (Figure D.4). When there is an increase in RVA, the higher the elasticity, the larger the increase in RVA (Models 1, 2, 3, and 7). Model 5 is an exception; the higher the elasticity, the smaller the increase in RVA. When there is a decrease in RVA (Models 4, 6, and 8), there is no consistent pattern in the direction of the change in RVA with varying elasticity values.

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[2] Results from varying the value of the elasticity of substitution in the effort function indicate that the variables are not particularly sensitive to the elasticity values across all model variants, and therefore these results are not reported in this paper but are available upon request.

[3] This study assumes that the rent is split between labor and capital based on their ratios to total value added in the two fish harvesting sectors in the base year. This study implements a sensitivity test to examine how the distributional results will change under an alternative assumption that all rent accrues to capital. The results of the analysis indicate that the effects of rationalization on effort, harvest, resource rent, and RVA are not found to be significantly different from the baseline case where rent is divided between labor and capital. Welfare change, however, is found to be rather sensitive, in terms of direction and magnitude of the change, to how the rent is distributed. More details are not presented in this paper, but are available upon request.

Results also demonstrate that when the aggregate household welfare increases, the higher the elasticity the larger the welfare increase (Models 1, 2, 3, and 7, Figure D.5). Again, Model 5 is an exception; the higher the elasticity, the smaller the welfare improvement. Models 4 and 6 predict that the welfare change is very small. When factors of production are perfectly mobile (Model 8), the welfare reductions are not very sensitive to values of the elasticity. While the magnitudes and the directions of the change in the aggregate welfare vary widely across Models 5-8, per capita welfare increases consistently in these model variants although the magnitudes of the increases are moderately sensitive to the stock elasticity in the model variants (Figure D.6).

*Sensitivity to catchability*

In each model variant, effort levels are moderately sensitive to changes in the catchability (Figure D.7). The higher the catchability, the smaller the reduction in effort in all the model variants. This is explained as follows. Suppose effort diminishes from $E_{OA}$ (its pre-rationalization level) to $E_{RA1}$ due to the rationalization *assuming that the catchability does not change*. Suppose further that at this effort level ($E_{RA1}$), the marginal productivity of effort is MPE1 which equals the unit cost of effort. Now *if the catchability rises due to the rationalization*, the marginal productivity of effort curve will shift up because the increase in catchability will make effort more productive. With the new curve, the marginal productivity of effort at effort level ($E_{RA1}$), denoted MPE2, will be higher than MPE1. This will incentivize fishing vessels to expand their effort level from $E_{RA1}$ to $E_{RA2}$ where the unit cost of the effort curve crosses the new marginal product of effort curve. The new effort level thus determined ($E_{RA2}$) will be lower than the pre-rationalization level of effort ($E_{OA}$) but higher than $E_{RA1}$. This means that in post-rationalization equilibrium, the net decrease in effort will be smaller if the catchability rises by a larger percentage, as illustrated in Figure D.7.

Compared to effort levels, harvest levels are more sensitive to changes in catchability (Figure D.8). For example, in Model 3, compared to its pre-rationalization level, harvest with fixed catchability is 38.8% smaller, whereas harvest is only 6.1% smaller with catchability that is 30% higher than its pre-rationalization level. Results reveal that the optimal level of harvest depends critically on how much catchability rises due to rationalization. It is found that in the case of Model 3, if catchability rises by 35.2% (not shown), the post-rationalization level of harvest reaches its pre-rationalization level. Not surprisingly, resource rent depends strongly on the catchability (Figure D.9). For example, in Model 1, the rent with rationalization is $14.2 million when the catchability does not improve, while rent is much larger ($19.0 million) if catchability improves by 30% due to the rationalization.

Compared to effort, harvest, and rent, changes in RVA and the aggregate welfare are much more sensitive to changes in catchability, especially in terms of the direction of the changes (Figures D.10 and D.11). For all model variants (except Model 8), the direction of the change in RVA depends on the catchability. For example, in Model 1, when catchability does not change with the regime shift, RVA declines slightly while it increases when catchability rises. In Model 8, the size of the decrease in the RVA varies substantially as catchability changes. It is shown that in Models 5-7, per capita welfare change is not very sensitive to the change in the catchability while it is rather sensitive in Model 8 (Figure D.12).

*Sensitivity to fixed level of harvest*

This study ran simulations to examine how results change if the harvest level remained fixed at the pre-rationalization level. Results demonstrate that the stronger factor mobility, the larger the increase in the catchability parameter required to maintain the pre-rationalization level of harvest. This study finds that the catchability parameter should rise by about 13% (Models 1 and 5), about 31% (Models 2 and 6), and about 35-36% in the other model variants to maintain the pre-rationalization harvest level (Not shown).

Reductions in effort are generally smaller with fixed harvest than with variable harvest (Figure D.13) with the exception of Models 1 and 5. On the other hand, rent is larger in general (except in Models 1 and 5) with fixed harvest than with variable harvest, and does not vary substantially across all model variants when the harvest level is fixed (Figure D.14). Rent with fixed harvest is $16.3-$16.4 million across all model variants. The RVA with fixed harvest does not diminish in all the model variants and doesn't noticeably change in some models (Models 5, 6, and 8, Figure D.15). Similarly, with fixed harvest, the aggregate welfare does not decline across all model variants and doesn't change at all in Model 8 (Figure D.16). Fixing the harvest level does not alter the magnitude of the change in per capita welfare significantly in Models 5-7 while it alters the magnitude moderately in Model 8 (Figure D.17).

## D.3 Discussion of sensitivity analyses

Sensitivity analyses for certain parameters reveal that the catchability parameter has the most critical influence on model outcomes. Among other things, this study finds that the optimal level of harvest or TAC for the rationalized fishery depends crucially on how much catchability rises under rationalization. Moreover, in most model variants (with the exception of 20% and 30% increases in the catchability parameter in Models 1 and 5), harvest diminishes consistently over the examined range of catchability change.

Related to this sensitivity analysis, this study also analyzes how results change if the harvest level is fixed at the pre-rationalization level. It was found that the greater the factor mobility, the larger the improvement in the catchability that is required to maintain the pre-rationalization level of harvest. For instance, Model 3 predicts that catchability should rise by at least 35.2% in order for the harvest level to be maintained at its pre-rationalization level and for resource rent to be maximized. Little is known about how much catchability changes due to rationalization. In the absence of knowledge about how fishing efficiency (measured by the catchability parameter) would change under a rationalization policy, fisheries managers may wish to keep the TAC at its pre-rationalization level. Sensitivity analyses conducted in this study highlight the importance of research on the degree and effects of efficiency change induced by a management regime change such as rationalization.

**Table D.1 Parameter values used in the sensitivity tests for Trawl sector**

| | Value of stock elasticity used | Value of elasticity of substitution used | Value of catchability parameter used | Rent distributed to | Harvest level |
|---|---|---|---|---|---|
| Baseline simulation | 0.585 | 0.61 | 0.0053 (20% increase) | Both labor and capital | Endogenous |
| Sensitivity test for stock elasticity | Low elasticity = 0.527<br>High elasticity = 0.644 | 0.61 | 0.0053 (20% increase) | Both labor and capital | Endogenous |
| Sensitivity test for elasticity of substitution | 0.585 | Low elasticity = 0.55<br>High elasticity = 0.67 | 0.0053 (20% increase) | Both labor and capital | Endogenous |
| Sensitivity test for catchability parameter | 0.585 | 0.61 | 0.0044 (No increase)<br>0.0048 (10% increase)<br>0.0057 (30% increase) | Both labor and capital | Endogenous |
| Sensitivity test for rent distribution | 0.585 | 0.61 | 0.0053 (20% increase) | Capital only | Endogenous |
| Sensitivity test for fixed level of harvest | 0.585 | 0.61 | Endogenously determined | Both labor and capital | Exogenous |

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## Figures

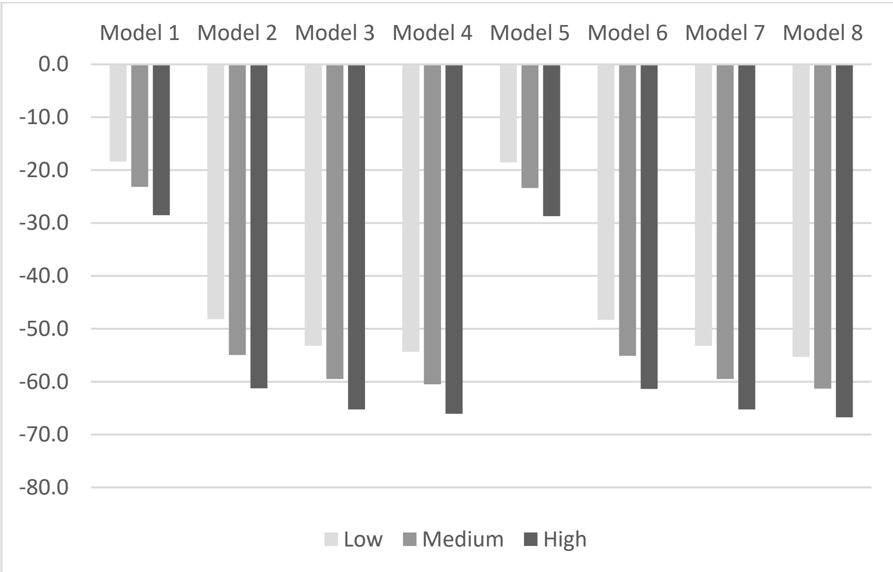


**Figure D.1 Percent change in effort with different values of stock elasticity**

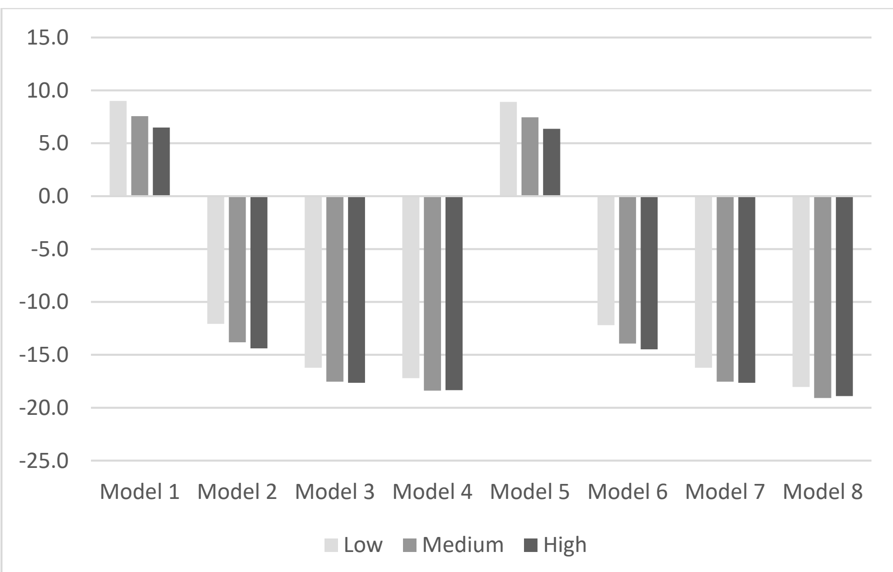


**Figure D.2 Percent change in harvest with different values of stock elasticity**

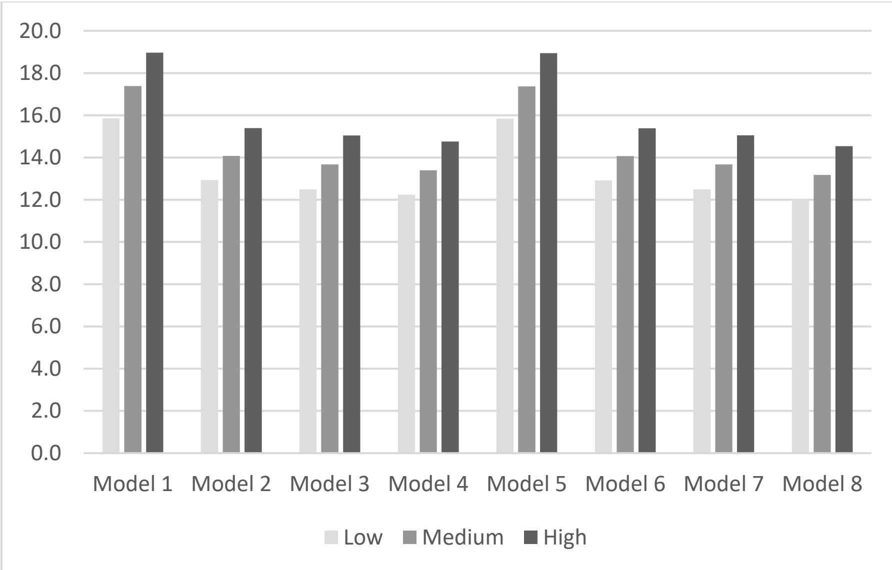


**Figure D.3 Rent with different values of stock elasticity ($million)**

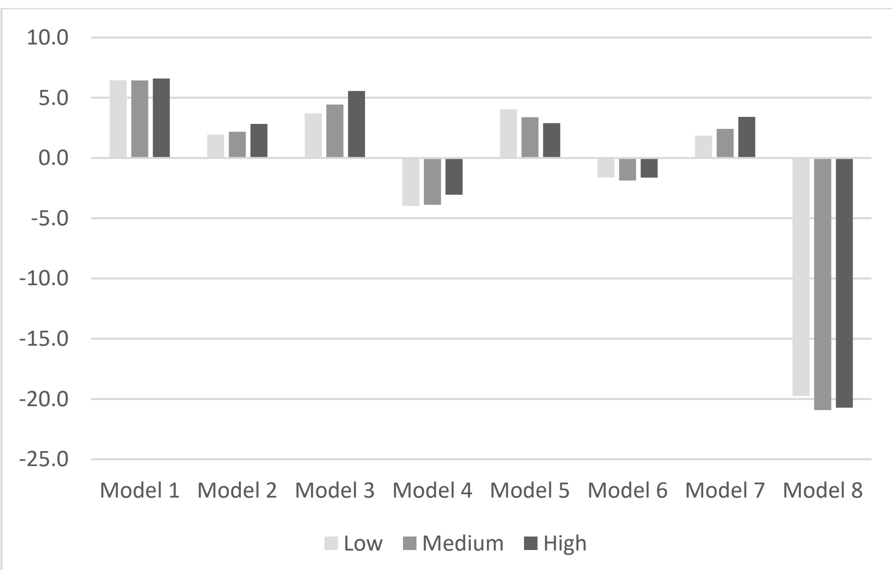


**Figure D.4 Change in regional value-added with different values of stock elasticity ($million)**

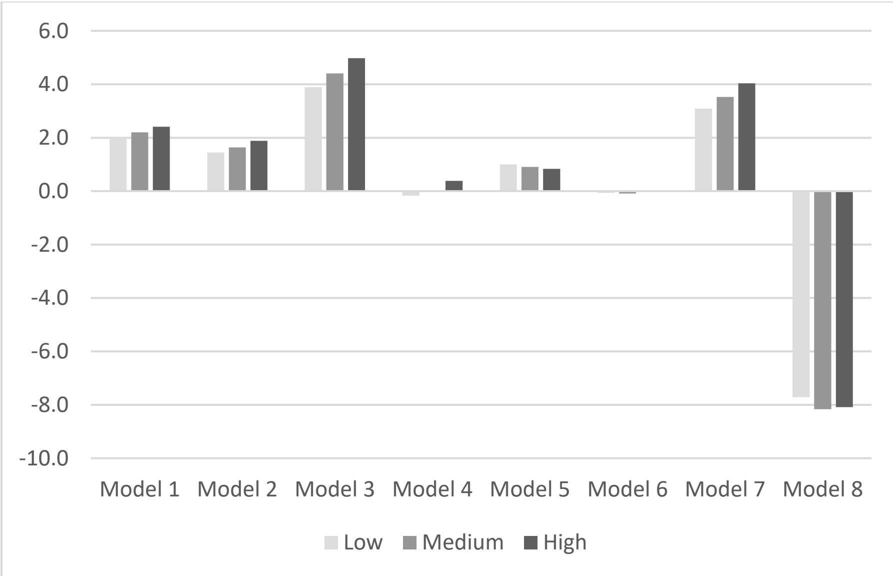


**Figure D.5 Welfare change with different values of stock elasticity ($million)**

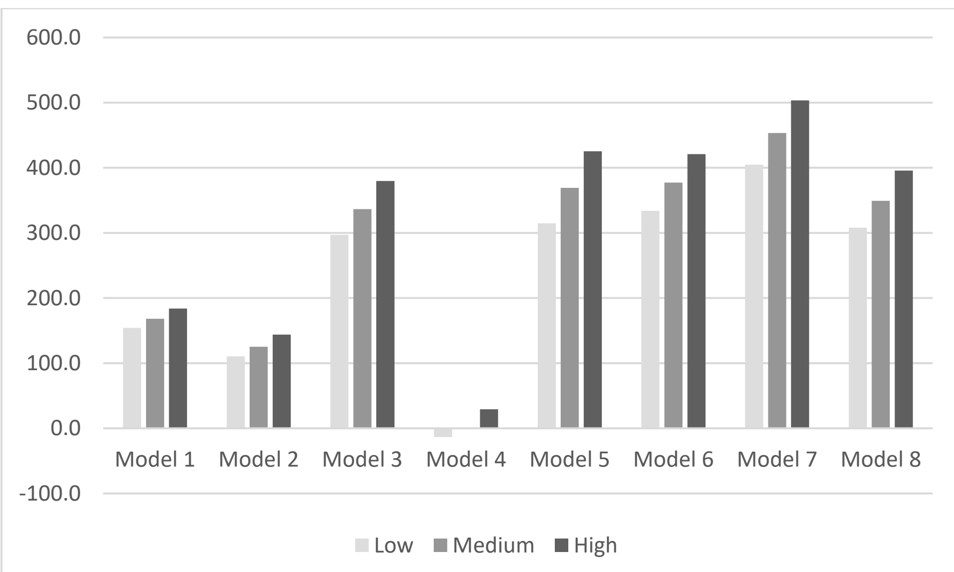


**Figure D.6 Per capita welfare change with different values of stock elasticity ($)**

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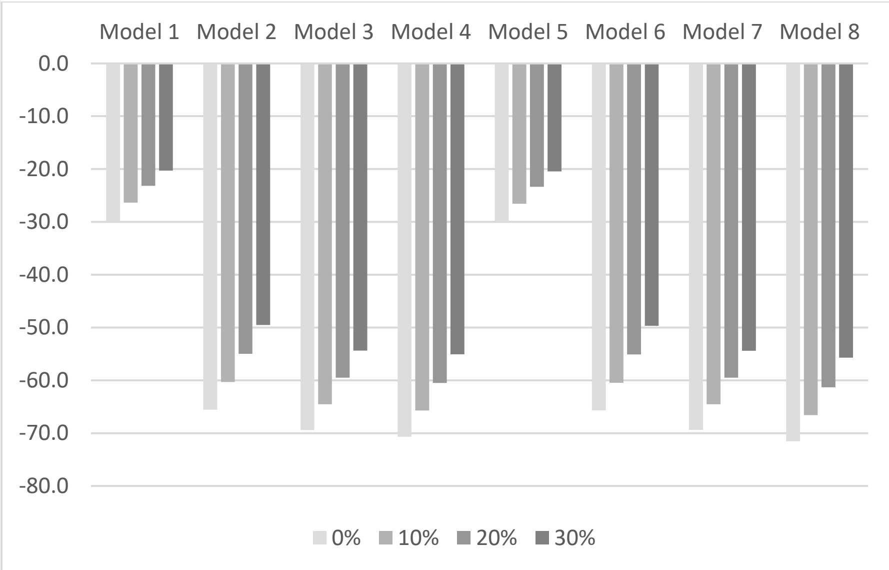


**Figure D.7 Percent change in effort with different values of catchability parameter**

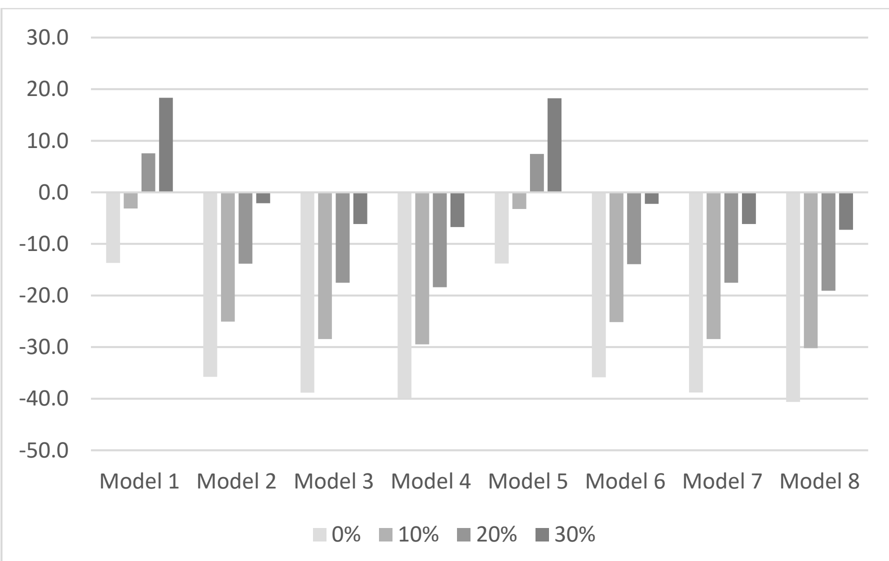


**Figure D.8 Percent change in harvest with different values of catchability parameter**

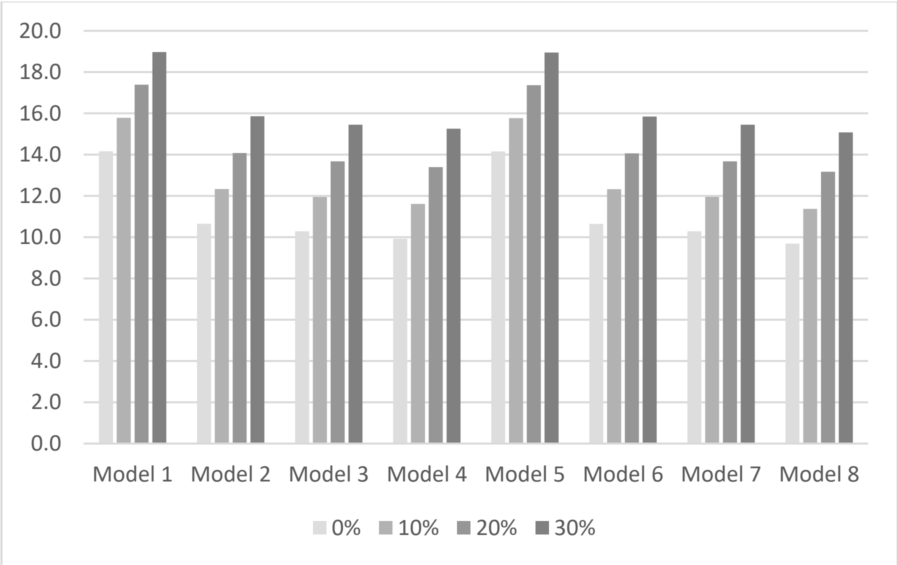


**Figure D.9 Rent with different values of catchability parameter ($million)**

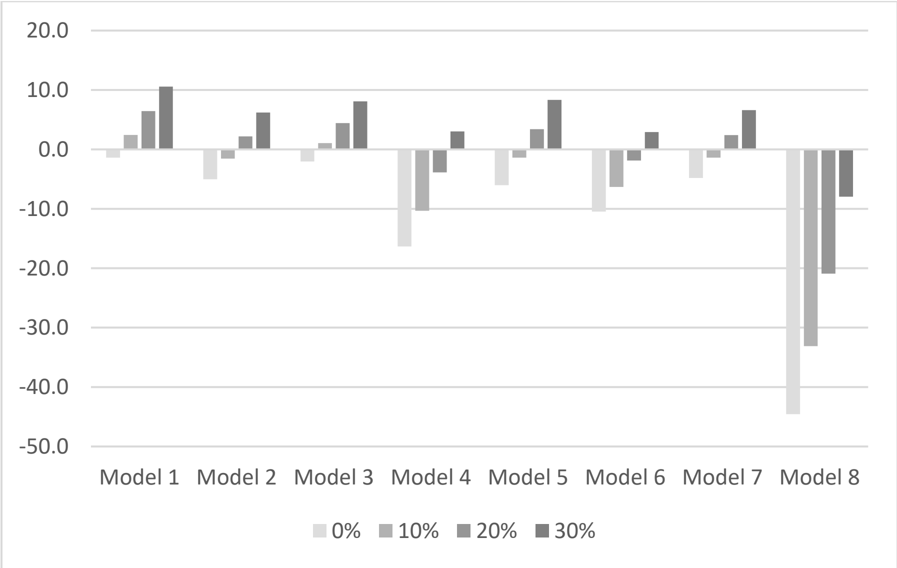


**Figure D.10 Change in regional value-added with different values of catchability parameter ($million)**

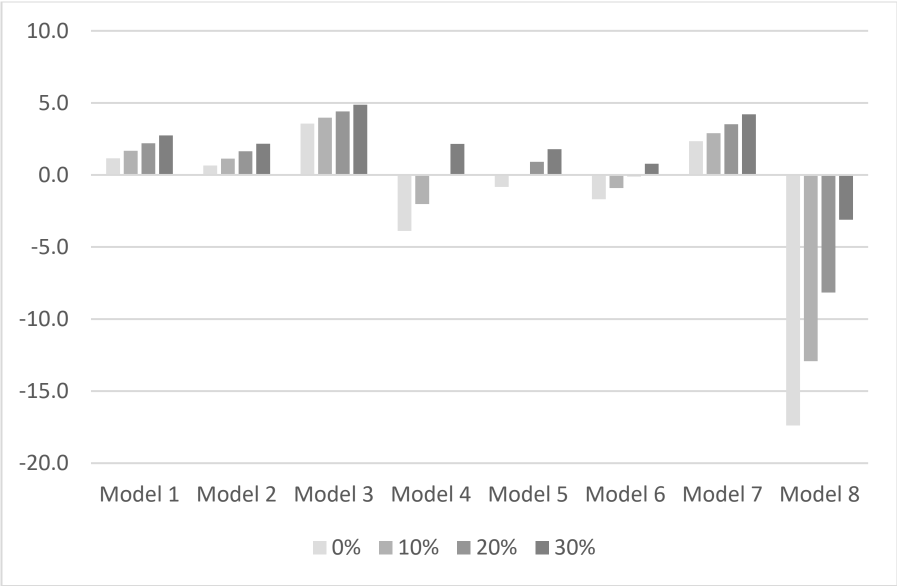


**Figure D.11 Welfare change with different values of catchability parameter ($million)**

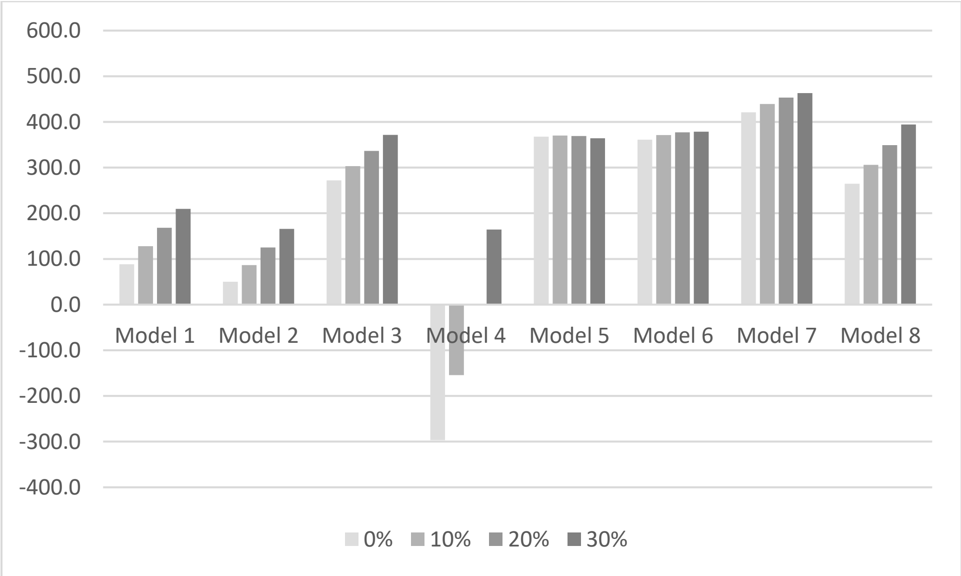


**Figure D.12 Per capita welfare change with different values of catchability parameter ($)**

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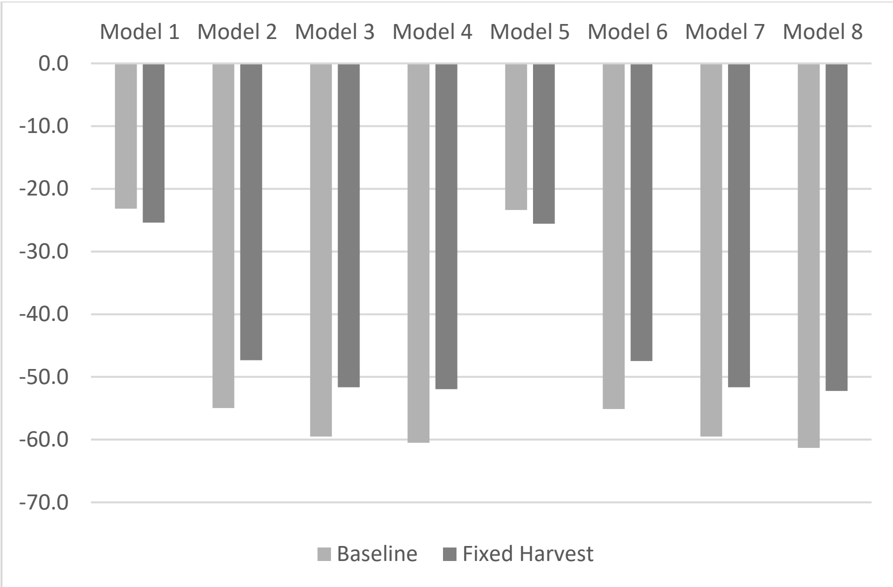


**Figure D.13 Percent change in effort with fixed harvest**

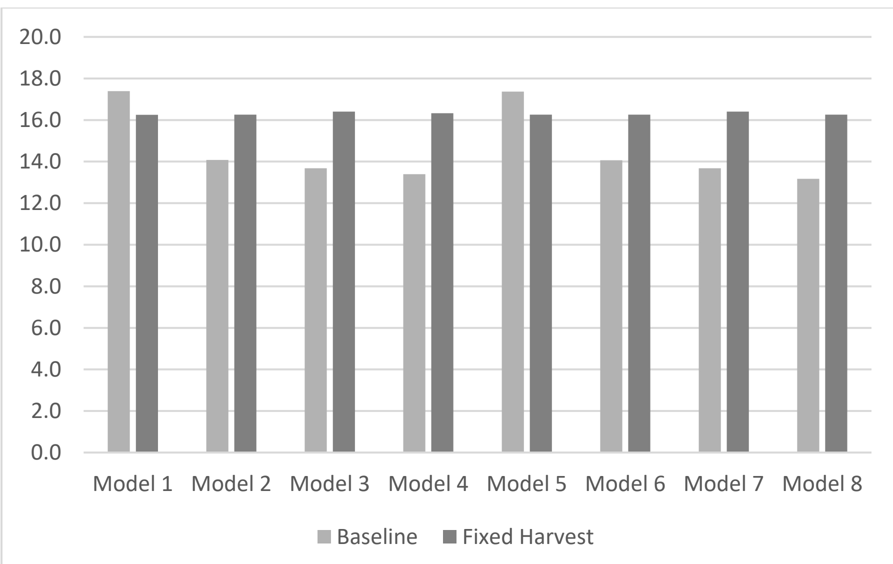


**Figure D.14 Rent with fixed harvest ($million)**

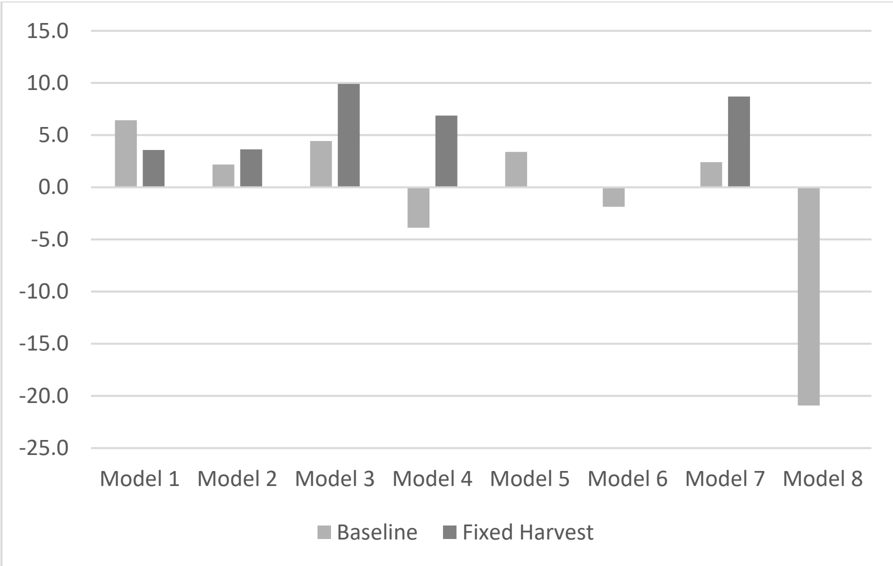


**Figure D.15 Change in regional value-added with fixed harvest ($million)**

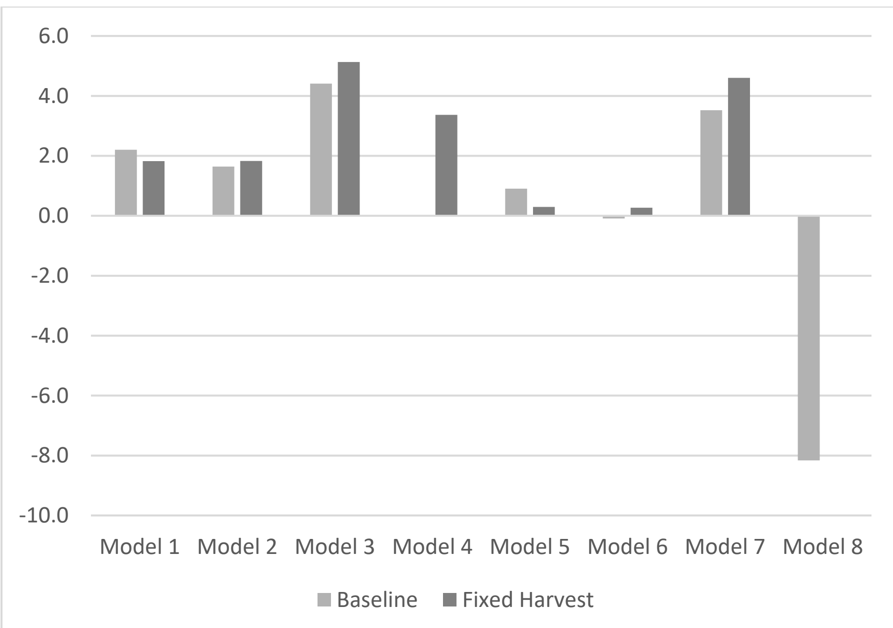


**Figure D.16 Welfare change with fixed harvest ($million)**

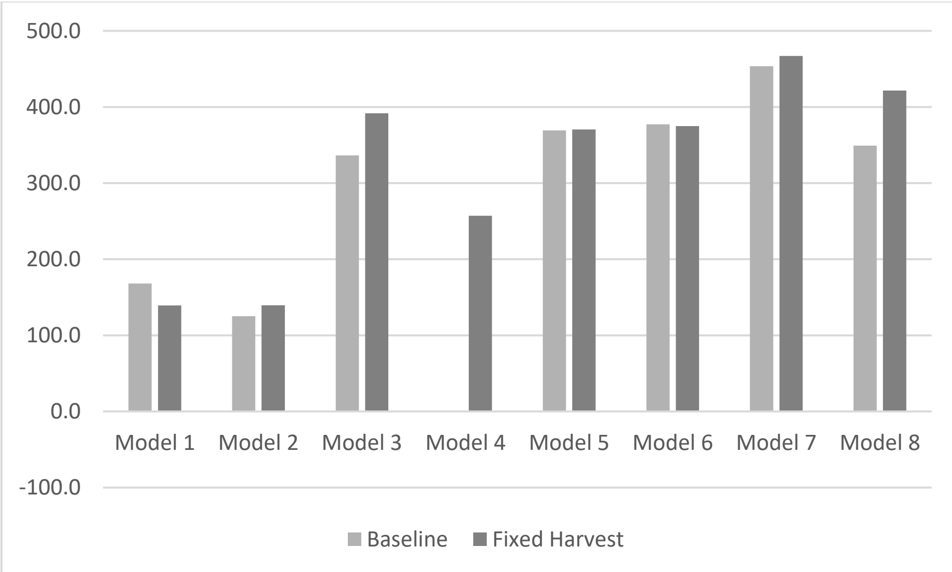


**Figure D.17 Per capita welfare change with fixed harvest ($)**

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